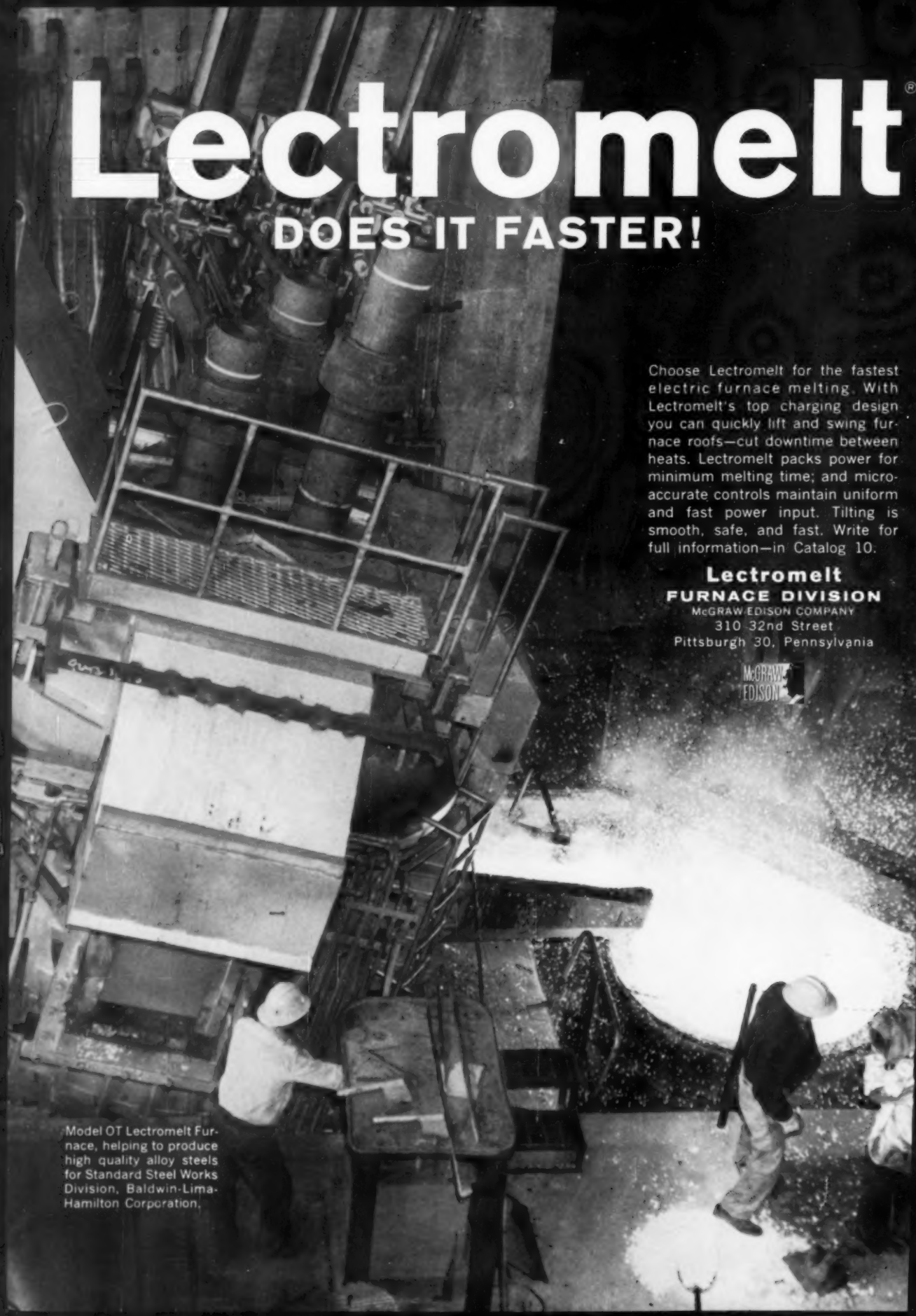
JOURNAL OF

METALS

AUGUST 1959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JOURNAL OF

METALS

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August, 1959

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PERSONNEL

► These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the national societies of Civil, Electrical, Mechanical, Mining, Metallurgical, and Petroleum Engineers, is available to all engineers, members and non-members, and is operated on a nonprofit basis. If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular employment fee of 3% of the first year's salary if a non-member, or 4% if a member. Also, that you will agree to sign our placement fee arrangement which will be mailed to you immediately, by our office, after receiving your application. In sending applications be sure to list the key and job number.

When making application for a position include eight cents in stamps for forwarding application to the employer and for returning when possible.

A weekly bulletin of engineering positions open is available at a subscription rate of $3.50 per quarter or $12 per annum for members, $4.50 per quarter or $14 per annum for non-members, payable in advance. Local officers of the Personnel Service are at 8 W. 40th St., *New York 18*; 57 Post St., *San Francisco*; 29 E. Madison St., *Chicago 1*.

— MEN AVAILABLE —

Metallurgical Engineer; B.S. physical metallurgy, age 24, married, family. No work experience. Desires position in quality control or production with growing company and good future. Available immediately; any location. M-963.

Metallurgist; M.S. Met.E., age 31. Five years deversified experience in steel mills and foundries, investment castings material development, heat treating, semi-conductors and nuclear materials, and research and development. Presently engaged in national research laboratory. Desires position in East. M-215.

Metallurgist; Belgian citizen with experience in European common market. Ingenieur des Mines, University of Louvain, Belgium; M.S. in Metallurgy, M.I.T., age 27. Two years working in mining industry. Desires position with opportunity for growth and responsibility. M-216.

Plant Engineer; ME (Canada), age 29. Has 3½ years experience as plant engineer over maintenance, utilities, transportation in mine smelting and refining; 1½ years as supt. of shops, maintenance, and transportation for mining company. Two years as junior engineer, designing and cost estimates for paper and board plant. $9000. Prefer Calif. or Midwest. S(M)-286.

Factory Manager; MetE (Canada), age 35. One and one-half years in sales of industrial furnaces; 7 years as asst. works mgr., foundry metallurgist, and casting metallurgist in steel foundry and products. $700. Prefer East or West. M-664.

Metallurgist; M.S.Me, age 30. Three years as asst. mill metallurgist, milling copper core; 1 year as a laboratory supv in plant control of titanium bearing products and titanium alloy ingot production; 9 months as metallurgist in tungsten ore; 1½ years as analytical chemist in U-Vores processing; 1 year as contract miner with Pb-Zn ore. $8000. Prefer South America or Rocky Mts. M-487.

Metal Parts Fabrication; AE, age 32. Eleven years as supervisor of technical services, new equipment and material in metal finishing, quality control, materials handling, production, and plant equipment. Heat treat, plastic molding, inspection methods and equipment all for automotive manufacturer. $9500. Prefer San Francisco, Los Angeles, or Calif. M-402.

Mill Foreman; MetE, age 23, One month as mineral test engineer in lab to promote sales of equipment for metallurgical manufacturer; 2 years as mill engineer in uranium processing mill and mine; 4 months as draftsman on mill design and construction. $550. Locate anywhere. S(M)-249.

Superintendent; MetE., age 39. One year as test engineer of copper smelting and refining for mining company; 6 years as smelter metallurgist, foreman, research plant foreman on smelting in refining copper and lead with mining company; 6 years as foundry man and teacher for steel foundry. $650. Prefer US or Mexico. S(M)-743.

Alloy Developer; MetE., age 40. Three years in charge of laboratory power metals and surface films; 2 years developing and fabricating beryllium, nickel, manganese, and copper alloys; 5 months using vacuum techniques; and 2 years research and development of new alloys for gas turbines, heat exchangers, in tube production. $11,000. Prefer West Coast. S(M)-1605.

Metal Working; M.S. ME, age 33. Two years in production, planning, tooling control and design; 3 years of process designing of machinery for production of mechanical and hydraulic test equipment; 2 years designing tools for manufacturer; 1 year drafting for research. $615. Prefer foreign. S(M)-1508.

Production Control; Chemist, age 34. Six months evaluating missiles' metals; 2 years preparation of aluminum billets for cold extrusion; 5 years precious metal refining and glass fiber production; 1 year of aluminum smelter analysis. Prefer San Francisco area. S(M)-1419.

Foundry Production; M.S. MetE, age 50. Seventeen years in quality control and processes for melting materials; 3 years of automobile tool hardening; 2 years as hardening

(*Continued on page 482*)

SEMICONDUCTOR ENGINEERS AND SCIENTISTS

An expanding program, the result of increasing production and sales of the 4-layer diodes and other semiconductor devices, is creating openings in basic research, advanced device development and application engineering.

Opportunities exist also in the techniques of device packaging, as well as crystal growing and diffusion in silicon.

Openings are currently available and others will develop. Your resume, which will be held in strict confidence, may be sent to the Director, Professional Employment. (E1-5 Shockley Transistor Corporation, a Subsidiary of Beckman Instruments, Inc., Stanford Industrial Park, Palo Alto, California.)

CHANGE OF ADDRESS

The Chicago office of the Engineering Societies Personnel Service, Inc., has been moved to Suite 812, 29 E. Madison St. The telephone number remains the same, however—STate 2-2748. It is hoped that the office will prove to be more centrally located, and more convenient to serve both employers and applicants.

TWO TEACHERS, Department of Metallurgy. One, department head, Ph.D. preferred, physical or process metallurgy. Teaching and research. Rank and salary dependent on qualifications. Apply President, Montana School of Mines, Butte, Montana.

METALLURGIST WANTED

Diamond saw manufacturer requires metallurgist of proven ability, technical knowledge and "know how" of manufacture and application of: diamond impregnated powder metal parts for sawing, drilling, grinding. Position can lead to top level management. Applications with details to

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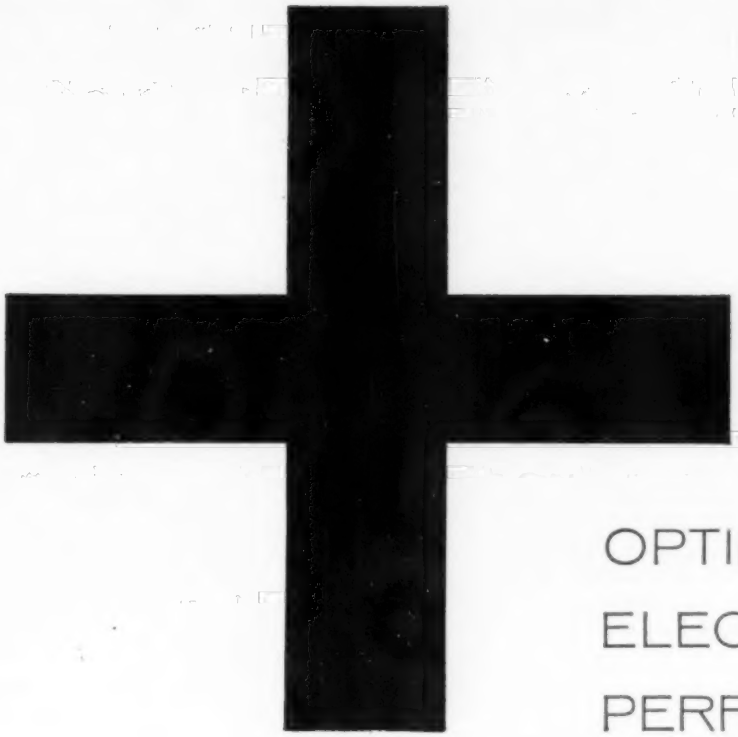

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PERSONNEL

(*Continued from page 480*)

furnace operator; intermittant teaching of special and general metallurgy. $10,000. Prefer South or West. S(M)-1283.

Production Planning; ME plus Bus Adm., age 39. Three years developing and producing new metal products for consumer and industrial use, managing, and merchandising; 2 years in plastic coatings. $650 up to start. Prefer San Francisco or West Coast. S(M)-1250.

— POSITIONS OPEN —

Sales Engineer; graduate metallurgist to develop sales for a new high-alloy foundry facility which will produce heat and corrosion-resistant castings for regular customers and a wider market. Duties will include direction of advertising and involve considerable application engineering for customer. Must have sales or customer contact experience. Salary commensurate with ability and experience. Apply by letter giving résumé of experience, salary requirements, and so on. Location, Midwest. W7651

Materials Metallurgist with B.S., M.S., or Ph.D. and 3 to 10 years experience in materials development to perform development investigations in area of atomic fuel element materials and core materials. Location, upstate N.Y. W7640(a)

Metallurgist and Metallographer with broad refractory materials experience, to supervise modern metallographic laboratory. Salary, $8000 to $10,000, plus company benefits. Location, New York area. W7632

Metallurgical Engineer; graduate with experience in low alloy and austenitic high-temperature alloys preferred, but will consider recent graduate. Assignment in process control laboratory of major automotive parts manufacturer. Work will cover forging, cold forming, heat treating methods. Salary, $6500 to $9600. Company pays placement fee. Location, Midwest. W7626(b)

Research Engineer and Secretary for trade association. Degree in engineering and/or metallurgy, preferably with some experience in tubular steel products and allied fields. Salary $10,000 to $12,00 to start. Location, New York. W7624

Research Engineer; M.S. or Ph.D. in mechanical or metallurgical engineering, physics, or civil engineering. Two to five years experience preferred. To conduct recearch in the following areas: theory of elasticity, theory of plastic flow and fracture, dislocations in crystalline structures, creep, fatigue and thermal shock. Should have strong scientific interest and be in forefront in application of strength of materials to industrial problems. Salary $8500 to $12,000. Company pays placement fee. Location, Midwest. W7529(a)

Sales Engineers for process equipment used in chemical, metallurgical, and sanitary fields. Preference will be given chemical and metallurgical engineers in the fields. Salary, $7000 to $10,000 base, plus commissions. Locations, New York, Chicago, and other cities throughout US. W7528

Metallurgical Engineer; graduate with 2 or 3 years experience in laboratory testing on research and development projects. Salary, $7280 to $7800. Location, northern N.Y. W7520

Design Engineer; mechanical or metallurgical graduate with at least 5 years design experience on industrial furnaces, preferably vacuum furnace type. Salary, $8000 to $9000. Location, N.J. W7518

Metallurgical Sales Engineer with B.S. in metallurgy or chemical engineering and at least 3 years experience in steel manufacturing. Will represent company in metallurgical sales accounts and improve relationship with customers for increased markets. Will provide customers with technical data for uses of metallurgical products, and maintain up-to-date knowledge of metallurgical markets, uses of products, and new developments. Travel approximately 60 pct of the time. Salary, $8000 to $12,000 to start. Company will negotiate placement fee. Location, Philadelphia area. W7503

Metallurgical or Mechanical Engineer with 8 to 10 years of process evaluation, including economics of process development, computing heat and material balances, compiling data into reports and analyses of complex, inorganic chemical processes. Salary, open. Location, South. W6772

Research Engineer; graduate in metallurgy, electronics, physics, or electrical engineering with considerable experience in top-level research in semi-conductors, preferably silicon rectifiers. Company has well-equipped laboratory for scientific research. Salary, $10,000 or more, depending on qualifications. Location, Ind. C7494

Administrative Assistant to chief engineer. Prefer graduate MetE, ME, or EE with at least 10 years supervisory experience in design estimating, or operation phases of metal mine plants, mills, concentrators, smelters, or refineries. Will be responsible for engineering dept. personnel, cost control, and special assignments or studies. Salary, $12,000 to $14,000. Location, western US. S(P)-4465-R

Physical Metallurgist to research and develop aluminum alloys and fabricating practices. Salary commensurate with education and experience. Location, Pacific Northwest. S-4441

Metallurgy Research Engineer; M.S. MetE, ChemE, or Chem (not mining) or B.S. with exceptionally strong research experience. Must be interested in applying knowledge to industrial problems rather than fundamental research. Dept. conducts applied research and development on new processes and major process improvements in fields of mineral beneficiation, hydrometallurgy, and pyrometallurgy. Salary commensurate with training and experience; liberal fringe benefits. Location, West. S(P)-4257

Sales Engineer; graduate in metallurgy or mining with several years practical experience plus commercial selling or purchasing ores and minerals. Will represent producting mines supplying iron ore to Japanese steel companies. Must be married, preferably with family. Salary open, plus free housing and business expenses. Location, Japan. S(P)-4400

Laboratory Manager; graduate in Met., Chem., or ChemE with supervisory experience or management background. With company specializing in quantitative analysis and metallurgical extractive field for mining and smelting companies. Location, Ariz. S(P)-4411

Assayer; for base metal concentrates. Recent actual working experience in practical analytical assays of ores or concentrates (copper, zinc, molybdenum, chrome, and so on). To isolate foreign or trace quantities and to assay and report prior to, during, and after production. Chemical sales processing company. Salary, $500 to $550. Location, northern Calif. S(P)-4349

Research Metallurgist; B.S. or M.S. qualified to deal with challenging metallography and metallurgical laboratory practices and studies. Prefer knowledge of powdered metals. Will assist in research and new product development of refractory metallurgy. Should have knowledge of physical chemistry, ability to use advanced laboratory equipment, tests and instrumentation, and possess an interest in electrolytical process development. With manufacturer's laboratory. Salary, $650 to $750 and up. Location, San Francisco Bay area. S(P)-4335R

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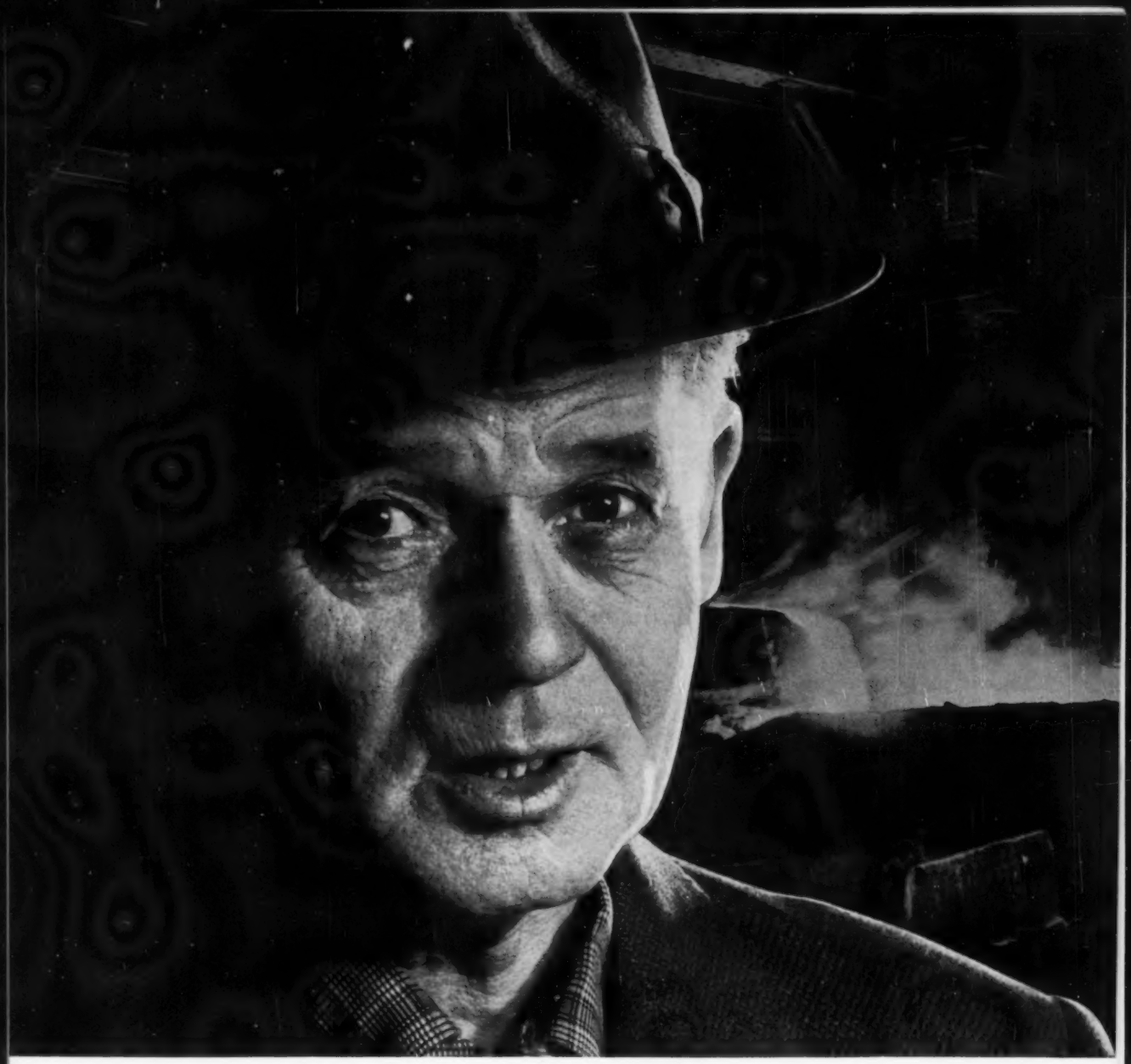

"Metallic yield goes up with pig-cast ferrosilicon"

Now steel producers can increase silicon recoveries and simplify handling operations with new ELECTROMET pig-cast 75% ferrosilicon. The pigs provide a convenient, uniform lump size for ferrosilicon additions to steel. They produce a higher, more consistent metallic yield because fines are practically eliminated. Ready solubility is achieved because pig additions penetrate the molten steel very quickly. The uniform shape and weight of the pigs (10 to 15 lbs. or 20 to 25 lbs.) make handling easier in both unloading and furnace operations. Your UNION CARBIDE METALS representative will gladly give you further information.

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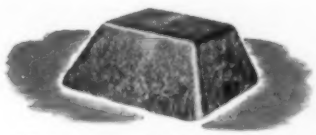

Pigs are easy to handle and give a high metallic yield.

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letters to the editor

Ferro coke

I have noted with interest your abstract of our paper on Ferro Coke in the June issue of the JOURNAL OF METALS in the article, *What Happened in St. Louis?*

Since the abstract mentioned that we expect to use up to 100 pct ferro coke in our furnace, I thought that you might be interested in knowing that we have now run our furnace using 100 pct ferro coke for 5½ weeks with excellent results.

M. J. Lach
Eastern Gas & Fuel Assoc.
Boston, Mass.

Process metallurgy

Sincere thanks for the timely editorial regarding the preponderance of physical (and also *nuclear*) metallurgy in the TRANSACTIONS, despite the mentioned availability of two publications expressly devoted to this subject. (JOURNAL OF METALS, June 1959, p. 363).

It is regrettable that the TRANSACTIONS are at present, useless to a production metallurgist: the occasional interesting articles are too well hidden in the flood of physics to be readily noticed or found without a formal library search. Furthermore, the contents are a stiffling deterrent, especially to the younger man, with regard to submitting information interesting to production men, but not suitable for development to the level of a highly polished doctoral thesis.

It would be welcome, and probably result in an increased number of subscriptions, if individual issues of the TRANSACTIONS could be devoted to each of the three divisions in turn. Hence, Extractive Metallurgy, Iron and Steel, and the Institute of Metals would each have four issues at their disposal yearly. The issues would not, necessarily, have to be of equal size. Any overflow would have to be directed to other publications.

A. T. Peters
Metallurgist,
Inland Steel Co.,
East Chicago, Ind.

Tops Building Goal

Pennsylvania-Anthracite section has topped its quota to the Engineering Center Building Fund with a pledge of $5685 to date. This figure amounts to an average pledge of $50.76. Section secretary Floyd S Sanders cautions, however, that they are still far short of their a-pledge-from-every-member goal.

RESEARCH METALLURGISTS

For Fundamental and Applied Research in Physical Metallurgy. Considerable latitude in choice of projects is provided and individual choice is encouraged. Areas of broad interests include high temperature alloys, cermets, magnetic materials, conductors, semi conductors, and abrasion resistant materials. Ideal spot for PhD's with several years experience and the desire to achieve success through personal initiative in research.

Write, giving details of educational background and prior work experience, to:

M. C. Rohm
Employment Section
Allis-Chalmers Mfg. Co.
Milwaukee 1, Wisconsin

personals

Italo S. Servi has been named director of research of the Metals div., Kelsey-Hayes Co. Dr. Servi will be in charge of the entire research and development activity of the division, which produces vacuum-melted alloys for jet aircraft and missile applications. A specialist in the behavior of metals at high temperatures and in corrosive environments, Dr. Servi is chairman of the Columbium and Tantalum Applications Panel for the Materials Advisory Board, National Academy of Sciences.

Stephen M. Jenks has been appointed vice president in charge of Engineering and research at U. S. Steel Corp. In 1956 Mr. Jenks received the AIME's Fairless Award for "distinguished achievement in iron and steel production and ferrous metallurgy. Mr. Jenks joined U. S. Steel in 1925 at the American and Tin Plate Co. in Pittsburgh. He became administrative vice president of central operations last year.

Alexander R. Troiano, head of the department of metallurgy at Case Institute of Technology, has been chosen to receive the Research Award sponsored by the Case Chapter of Sigma Xi. A plaque and a $100 honorarium are being given to Dr. Troiano in recognition of his "extensive research investigation" in the metallurgy of steel and titanium alloys.

Sidney Siegel has taken over the post of executive vice president of the U. N. Alloy Steel Corp., Boston. Mr. Siegel was formerly mgr. of engineering, nuclear products div., Metals & Controls Corp.

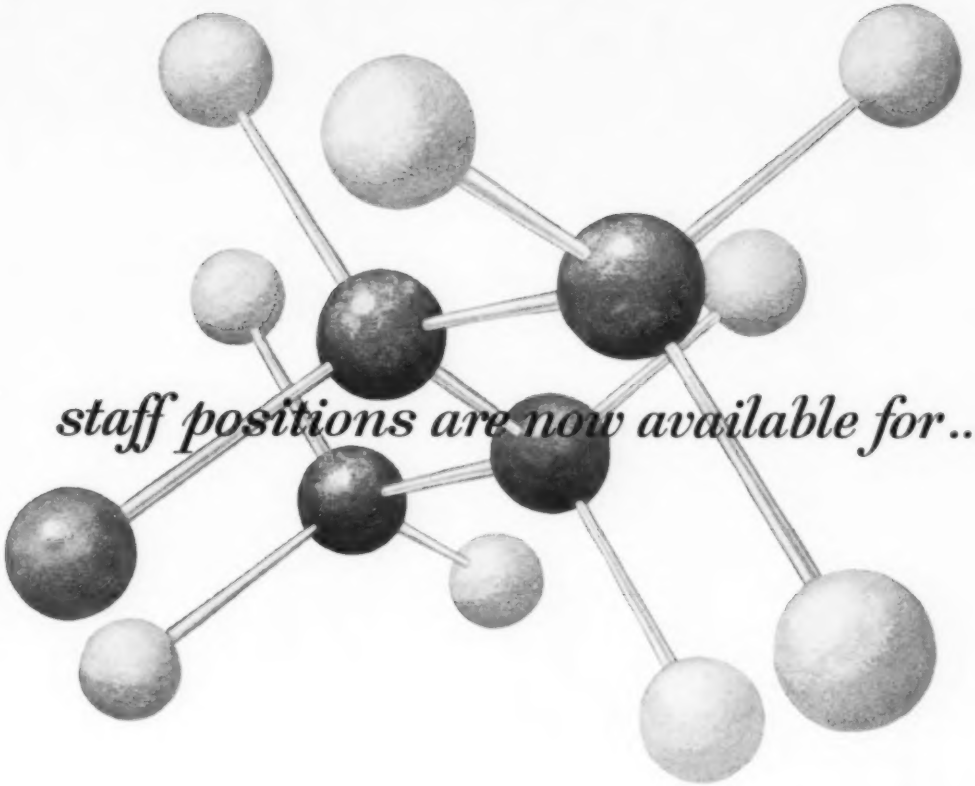
W. W. Heilman has been promoted to assistant manager of the Niagara works of the Union Carbide Metals Co., div. of Union Carbide Corp.

W. M. Kelly, another AIME member, will take over Mr. Heilman's former position as assistant technical director of alloys, the Technical Control Group at the Niagara works.

Al Thurman has been named president of The Lombard Manufacturing Co., and vice president of the Lombard Corp., headquartered in Youngstown, Ohio. Just prior to his appointment, Mr. Thurman had served as a management consultant and counseling engineer to heavy industry.

Frank Coolbaugh has been elected president of the Climax Molybdenum

(*Continued on page 488*)



staff positions are now available for.....

Argonne provides a unique combination of basic and applied research . . . effective interdisciplinary approach to major problems . . . dedication to knowledge of interest and significance to the individual . . . atmosphere and facilities conducive to creativity . . . opportunity for professional growth and individual expression. The positions described represent some of the Laboratory's specific opportunities. However, staff positions are available in virtually all of the major scientific and engineering disciplines.

- **Ph.D. Physical Metallurgists or Metal Physicists** for basic studies in metal alloy theory, high temperature ceramics, plasticity and high temperature strength, crystal structure and interjections, diffusion and irradiation effects. Excellent facilities available for x-ray and neutron diffraction, optical and electron microscopy, magnetic measurements and irradiation. Positions available for experienced research scientists and recent Ph.D. graduates. Several positions available at the group leader level with technical supervision responsibilities.

- **B.S.-Ph.D. Metallurgical Engineers, Metallurgists, and Ceramists** for interesting projects in applied metallurgy and metallurgical engineering. Areas of responsibility include property determinations and measurements, radiation damage, nuclear fuels and fuel elements, foundry fabrication, welding, and non-destructive testing. Involves working with uranium, plutonium, and other fission materials.

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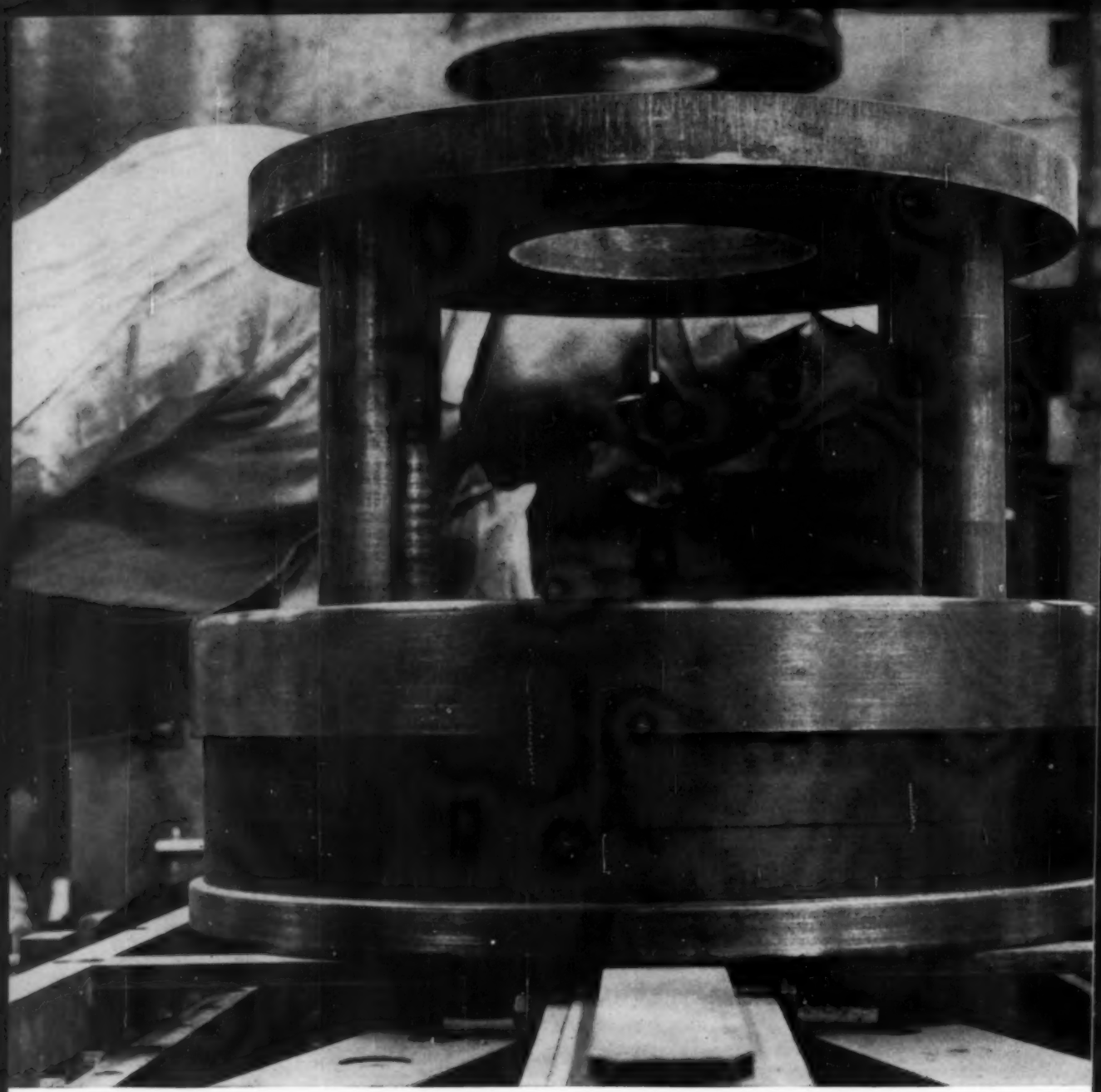

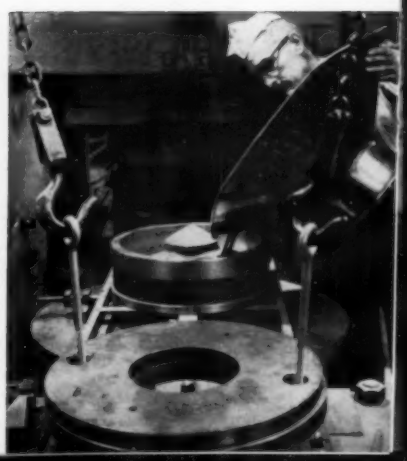

Here's a tough old squeezer that won't wear out

The donut-shaped steel disc in the main illustration is the mold plate used in a large hydraulic press. Under 2,000 tons of pressure, it squeezes an abrasive mixture in a mold to make grinding wheels. It's a tough job, and Waltham Grinding Wheel Company had to replace these discs every few months because they wore down and became unbalanced. Replacements were expensive and they wasted production time.

Finally, Waltham tried a plate made of USS "T-1" Steel. It has been used for more than a year now, and Waltham engineers say it will last indefinitely.

"T-1" constructional alloy steel has a minimum yield strength of 100,000 psi. It is exceptionally tough and resistant to abrasion—can be furnished heat treated to a minimum hardness of 321 Brinell. Compared to carbon steel, it has four times more resistance to atmospheric corrosion. In spite of its strength and toughness, "T-1" Steel can be formed, machined and welded. And because of its strength, it can be used in lighter gages, reducing weight as much as ⅔, depending on the application.

If you would like to have complete information about "T-1" Steel, write for our book "USS 'T-1' Steel," United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

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RARE EARTH AND YTTRIUM METALS

In your unceasing search for promising new materials for metallurgical applications, you are sure to find it interesting and provocative . . . and quite likely rewarding . . . to investigate the rare earths.

Rare earth and yttrium metals are readily available from our inventory in a wide range of purities in experimental quantities. Primary forms are ingots, lumps and turnings. Costs are reasonable and advantageous for your research or product development operations.

Lindsay rare earths cover the whole gamut of rare earth technology, from crudes to highly refined materials. One of the significant properties of the rare earth metals is their scavenging ability for oxygen, sulfur, and some other non-metallics.

LOOK AT YTTRIUM, TOO

Yttrium shouldn't be overlooked either. It is available in grades ranging from high purity to crude alloys with magnesium.

Lindsay has been working with the rare earths for nearly 60 years, and is the world's largest producer of rare earth, yttrium, and thorium materials. We can furnish you with a considerable amount of interesting and revealing technical data on rare earth and yttrium metals, including a detailed tabulation of properties, purities, and costs.

Please ask for our bulletin "Rare Earth and Yttrium Metals." It will be sent to you promptly.

TRONA

LINDSAY CHEMICAL DIVISION

American Potash & Chemical Corporation

99 Park Avenue, New York 16, New York

•

3000 West Sixth Street
Los Angeles 54, California

PERSONALS

(*Continued from page 484*)

Co., div. of American Metal Climax Inc. His move to the company's executive offices in New York City caps a career begun as a miner's helper in its molybdenum mine in Climax, Colo.

Gerald Pincus has become a project engineer at the Materials Research Corp., Yonkers, N. Y. Mr. Pincus previously served eight years on the research staff at Columbia University.

Oscar Pearson is now administrative vice president of the steel producing divisions, production dept. of U. S. Steel Corp.

Robert G. Vervaeke is the new manager of the Pascagoula works, Pascagoula, Miss., refractories div. of H. K. Porter Co., Inc. Mr. Vervaeke was formerly general mgr. of the Chemical Lime Co. at Baker, Ore.

Bruce Gonser celebrates 25 yrs of service in research at Battelle Institute this year. Head of tin research at the Institute, Mr. Gonser is regarded as an authority in tin technology. He was among the first to undertake research on deposition and coating of metals by decomposition of vaporized metal halides.

Harry Czyzewski, president of Metallurgical Engineers, Inc., Portland, Ore., has been elected national director of the Consulting Engineers Council, representing the Consulting Engineers Association of Oregon.

John Fuqua has been named chief plant metallurgist at the Copper Alloy Corp., Hillside, N. J. Mr. Fuqua will direct pattern planning and making, sand control, operation of the ladle and melting, the chemical laboratory and X-ray depts. of the stainless steel valve, fitting, and casting manufacturer.

Dillon Evers has been named mgr. of the newly-formed Sponsored Research Group at Mallory-Sharon Metals Corp., Niles, Ohio. The Group will carry out research and development projects on special metals for the Government. One of the first tasks faced by Dr. Dillon's researchers will be to construct and test a cold crucible furnace which will eliminate contamination problems created by conventional crucible materials.

Harry C. Stumpf has been promoted to the position of senior scientist at the Alcoa Research Laboratories of the Aluminum Company of America, New Kensington, Pa. Dr. Stumpf's work at Alcoa has been primarily in the field of X-ray diffraction and electron diffraction. He is currently investigating precipitation in aluminum alloys by means of electron diffraction.

SENIOR RESEARCH METALLURGIST
RHOANGLO MINE SERVICES, LIMITED

A Senior Research Metallurgist is required for research and development work in the field of non-ferrous ore dressing and metal extraction processes of all kinds, with particular reference to copper, cobalt, lead and zinc.

Rhoanglo Mine Services, Limited provides consultant services to the Northern Rhodesian copper companies directed by Anglo American Corporation of South Africa, Limited, and to the Rhodesia Broken Hill Development Company, Limited. Several development projects are conducted simultaneously by staff of approximately 40. Development normally progresses from the laboratory to tonnage scale pilot operation.

Applicants should have approximately ten years experience in applied research and/or operations with an emphasis on Plant and Process development. Only applicants experienced in team leadership will be considered. Executive ability would enhance future prospects.

Location:—Kitwe, Northern Rhodesia has an equable climate and is a modern township with all facilities.

The commencing basic salary would be in the range of £1,800-£2,160 sterling per annum. In addition to basic salary, the position carries a variable cost of living allowance, at present approximately £6 per month and a variable metal bonus which at present is about 25 per cent of basic salary. There are generous pension, life assurance and medical benefits, and housing complete with basic heavy furniture is available at a nominal rental. Paid leave, which may be accumulated up to a maximum of three years entitlement, is at the rate of 51 days per annum. Transportation to Northern Rhodesia will be provided for the successful applicant.

Applications stating age, martial status, qualifications and experience, together with a recent photograph and the names of two referees should be addressed to, The Secretaries, Rhoanglo Mine Services, Limited, P.O. Box 172, Kitwe, Northern Rhodesia.

MATERIALS & FABRICATION PREVIEW

of the SOARING 60's

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International Amphitheatre, Nov. 2-6, 1959

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Cooperating Activities: The Metallurgical Society of AIME; Society for Non-destructive Testing, Inc. Associations presenting technical sessions in cooperation with ASM: Metal Powder Industries Federation; Metal Treating Institute; Ultrasonic Manufacturers' Association; Special Libraries Association—Metals Division; American Society for Testing Materials—Committee B-9; and the extensive programs of the American Society for Metals with the William Park Woodside Memorial Sessions, and Metallurgical Seminar.

new books

Books that are marked (•) may be ordered through AIME. Address Irene K. Sharp, AIME Book Dept., 29 W. 39 St., New York 18, N. Y. A discount is given whenever it is possible.

Dendritic Crystallization, by D. D. Saratovkin, Consultants Bureau Inc., New York, 126 pp., $6.00, 1959—Translated from Russian, this 2nd edition has been revised to include fresh material derived from observations under the stereoscopic microscope. The bulk of this volume contains many original and unpublished ideas and observations, and is an example of the modern microscopic approach to the crystalline state by an experienced worker concerned with the infinite variety of real crystals. Line diagrams and sets of stereoscopic photographs are included. •

Guide to the Literature of Mathematics and Physics, by N. G. Parke, III, Dover Publications, New York, 436 pp., $2.49, 1958—One of the features of this paperback edtion is an up-to-date listing of agencies and individuals who are engaged in Russian translation programs. The *Guide* lists more than 5500 key words under subject headings such as projective geometry, geometric optics, and cosmic rays. Titles are cross-referenced. Lists of indexes, documentary reproductions, abstracts, and other bibliographic aids are included. •

Coated Abrasives-Modern Tool of Industry, edited by Harold B. Maynard, McGraw-Hill Book Co. Inc., New York, 452 pp., 546 ill., $8.50, 1958—Prepared under the auspices of the Coated Abrasives Manufacturers' Institute, this volume covers many recent advances in the use and selection of coated abrasives via information on types, economic advantages, applications, and efficient methods of use. All factors of effective usage in the metalworking and plastics industries are described. •

Progress in Semiconductors, edited by A. F. Gibson, R. E. Burgess, and P. Aigrain, John Wiley Sons Inc., New York, 210 pp., $8.50, 1958—Volume 3, following the example set by its predecessors, has selected a limited number of topics taken from the whole field of semiconductors. Included in this edition: magnetoresistivity of germanium and silicon, chemical purification of germanium and silicon, electronic conductivity of silver halide crystals, silicon junction diodes, lifetime of excess carriers in semiconductors, scattering and drift mobility of carriers in germanium, and electronic processes in cadmium sulphide. Extensive references aid in further reading selections. •

The Theory of the Properties of Metals and Alloys, by N. F. Mott and H. Jones, Dover Publications, New York, 326 pp., $1.85, 1958—Originally published in 1936 by Clarendon Press, and reprinted from corrected sheets, mathematical models are developed to explain the properties of pure metals and to show how crystal structure, magnetic susceptibility, and electric and optical properties are interrelated. Quantum mechanical methods are also applied to the problem of metallic cohesion. •

Refractories Bibliography, 1947 to 1956, University of Oklahoma Press, Norman, Okla., 1822 pp., $7.50, 1959—Compiled by The Joint Refractory committee of the AISI and the Refractories Institute, this new bibliography contains more than 9500 references to the periodic literature and to US foreign patents on refractories, continuing the compilation of the previous edition which covered 1928 to 1947. Refractories in all phases of industrial use have been covered. References are arranged by author and cross referenced as to subject. •

Produktenboek (Metal Products from Holland), Vereniging van Metaal-Industrieen Den Haag Nassaulaan, The Netherlands, 783 pp., 1958—Supported by their own and collective scientific research and development investigations, and due to large investments, the Dutch metals men feel the industry has reached a level on which its competition is exceptionally successful. The Association of Metalworking Industries in The Hague has compiled this volume in order to meet the demand for a survey of what is manufactured in the Dutch metalworking industry. The book consists of product lists,

(Continued on page 496)

Personnel

(Continued from page 482)

Steel Mill Designer with at least 15 years complete steel mill design, including 3 years actual work in steel operations and several years top project engineering level working with management, client, and design dept. Must now be working on design layout of blast, open hearth, oxygen lance and main equipage, including equipment and building layout. With engineering builder. Salary, $15,000 level. Relocation and placement fee paid by employer. Apply by letter in confidence. Location, San Francisco. S(P)-4277

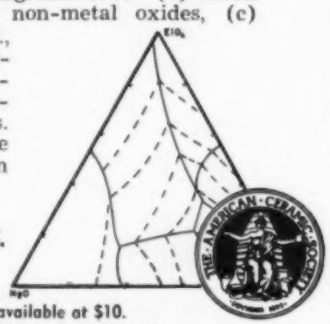
Refractory Research; B.S. or M.S. in metallurgy, preferably with knowledge of powdered metals. Must be qualified to deal with challenging metallography and metallurgical laboratory studies relating to new product development of refractories. Should have knowledge of physical chemistry and be able to use advanced laboratory equipment for testing and instrumentation. Interest in electrolytical process development desirable. Salary, $650 to $750 and up. Location, Central Calif. coast. S(P)-4142

Just Published

Phase Diagrams for Ceramists: Part II

ERNEST M. LEVIN and **HOWARD F. McMURDIE.** Edited and published by the American Ceramic Society, Inc., Columbus 14, Ohio, 1959. 153 pp. $8. (Cash with order, postage prepaid.)

This supplement contains 462 phase diagrams collected after those published in the Part I (1956). Diagrams cover (a) metal oxide systems, (b) systems containing non-metal oxides, (c) systems containing halides, sulfides, etc., and (d) water-containing systems. Reflecting current interests, this issue contains many diagrams dealing with electronic ceramics and nuclear ceramics. Complete author and system indexes are given for the 1273 diagrams contained in the two volumes.



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The Extractive Metallurgy Division consists of men who work in extraction, smelting, and refining of non-ferrous metals. Here, as throughout the Society, a balanced program results in professional growth through membership.

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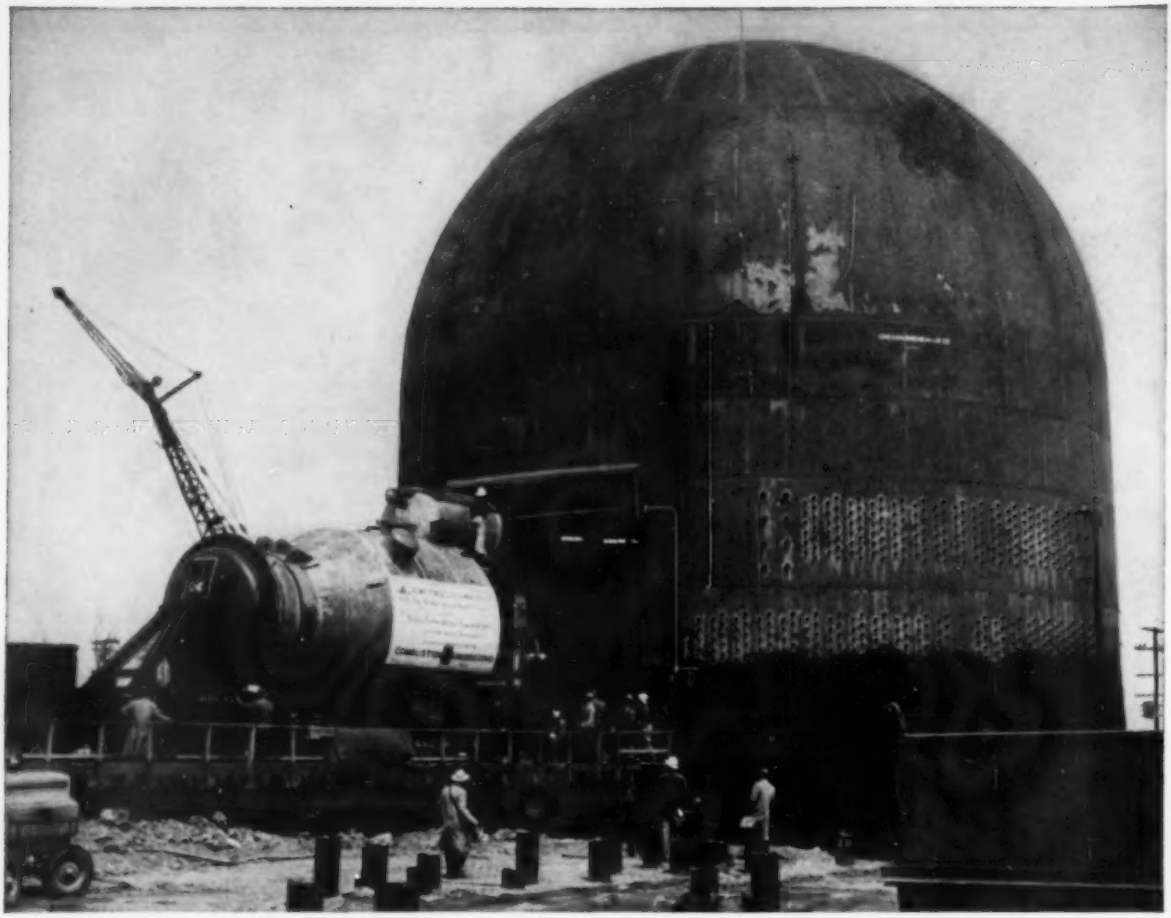

Atoms for Peace. This dome houses the 91-ton reactor vessel made of nickel-containing stainless steel for the new Enrico Fermi Atomic Power Plant on the shore of Lake Erie near Monroe, Michigan. Detail design and construction of the reactor vessel was done by Combustion Engineering, Inc. Plant will be built and operated by Power Reactor Development Company from designs supplied by Atomic Power Development Associates, Inc.

Atomic reactor "breeds" its own fuel

Stainless steel vessel must withstand high temperatures and corrosives

The world's largest full-scale nuclear reactor of the "fast-breeder" type is now being built. It may well answer the question:

> *When will atomic power be competitive with conventional methods of producing electric power?*

As the term "fast-breeder" indicates, the atom-splitting process is maintained by so-called *fast* or high-energy particles. It produces more nuclear fuel than it consumes. The fast-breeder actually turns out a kilogram and a fifth of new fuel for each kilogram it burns up!

The "breeding" takes place in a 36-foot high pressure vessel. Here, the high-energy particles (neutrons) travel at speeds of thousands of miles per second to keep the atom-splitting chain reaction going.

Accent on safety. A major objective was to make this reactor vessel safe. That called for a lot of highly specialized work.

It also called for a rugged metal: one capable of withstanding the tremendous heat given off in nuclear fission, and of bearing up under the temperatures and corrosives encountered. The final choice? Strong, corrosion-resisting Type 304 stainless steel. It's a stainless steel that contains Nickel – one of the big reasons for these superior properties.

How to "fast-breed" ideas. Problems involving reactor materials may never be a concern of yours. But you can run into *metal selection problems* involving corrosion, pressures, high temperatures and other destructive conditions almost any time. When you do, remember there is a good chance that a steel containing Nickel will provide the properties you want. Let us help you find out.

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NICKEL MAKES ALLOYS PERFORM BETTER LONGER

Steel expansion features oxygen

The Colorado Fuel & Iron Corp. plans to build oxygen converters with a 600,000-ton annual capacity at Pueblo, Colo.

In Weirton, W. Va., meanwhile, Air Products Co. has been awarded a contract to construct a high-purity oxygen plant for Weirton Steel Co., div. of National Steel Corp. The plant will have a capacity of 650 tons of oxygen per day . . . the largest for a single steel plant in the US. The plant's output will primarily be used to increase steel production in the company's open-hearth furnaces. Weirton Steel's present 450-ton oxygen plant capacity is consumed in its four blast furnaces.

Plan Quebec direct-reduction

The first full-scale commercial use of the Strategic-Udy process of direct smelting is reportedly destined for a plant to be built at Varennes, Quebec, Canada. Quebec South Shore Steel Corp. will locate the plant on a 200 acre site on the south shore of the St. Lawrence River.

A $12 million expenditure is going into the operation which, when completed, will produce more than 100,000 net tons of pig iron and semi-steel annually.

Make vanadium-boron alloy

Development of a vanadium-boron alloy that confers non-aging properties on steel has been announced by the Vanadium Corp. of America. As little as ¾ to 1¼ lb of the alloy is needed per ton of rimmed steel to give non-aging properties to the cold rolled sheet made from the steel, it is reported.

Two grades of the alloy are currently being produced. Alloy I contains 40 to 45 pct V, 7 to 9 pct B, 4 to 6 pct Ti, a max 2.5 pct Al, and not more than 10 pct C. Alloy II, contains 40 to 45 pct V, 7 to 9 pct B, no Ti, a max of 2.5 pct Al, and a max of 0.10 pct C.

Ready Kennecott refinery

Kennecott Copper Corp.'s new eastern refinery is scheduled for completion later this year. The Maryland refinery represents the last major step in Kennecott's integration of its copper producing facilities, including mining, milling, smelting and refining. Future plans call for a small increase in refinery capacity by 1965. Plans are also underway for a $10 million modification project designed to cut operating costs in the Company's newly-acquired Garfield, Utah, smelter.

Study radiation effects on steels

A major large-scale investigation of radiation effects on steels is being undertaken jointly by General Electric Co. and U. S. Steel Corp. It is expected that this testing and development will provide new steels with superior properties that will reduce the operating costs of nuclear power plants and hasten the advent of economic nuclear power.

In one phase of the program, corrosion resistance of a wide variety of steels is being carefully studied under conditions simulating those in actual boiling-water reactor service. Steels which exhibit superior corrosion resistance in these screening tests will then be exposed in the General Electric Test Reactor (GETR) under the actual operating conditions of corrosion and radiation. GETR is located at the G.E. Vallecitos Atomic Laboratory near Pleasanton, Calif. Information provided by these tests will be applied to the development of new and more economic steels particularly suited to use in boiling-water reactors.

In another part of the program, the effects of high-intensity neutron irradiation on the properties of reactor pressure-vessel steels will be studied in the GETR. (See the article on p. 523)

Steel specimens will be encapsulated and inserted in the reactor, where they will be subjected to intense neutron fluxes at temperatures of 150° and 600° F. Mechanical properties and the microstructure of each steel will be determined before and after irradiation.

AEC mill to close

The US Atomic Energy Commission will close its uranium mill at Monticello, Utah, on or about Jan. 1, 1960. The mill, the only Commission-owned uranium ore processing plant, will be maintained in a stand-by condition.

At present the mill, under contract to the National Lead Co., Inc., is treating uranium ores at the rate of about 300 tons a day—the minimum economic operating rate. However, ore deliveries in recent months have averaged only 100 tons a day, and a substantial part of the mill feed has been drawn from accumulated stockpiles. In order to operate at a 300-ton per day rate after Jan. 1st, the AEC would have to purchase a large quantity of ore in excess of programmed requirements.

With the closing of the Monticello mill, all domestic ore processing will be carried on by private industry. Twenty-two privately-owned mills, with a total capacity of approximately 20,650 tons of ore per day, are in operation throughout the western states.

REPORTER

Boom in cesium, rubidium

Production and consumption of cesium and rubidium increased several times in this country during 1958, according to a US Bureau of Mines report. New uses which gained attention during the year included a cesium plasma thermocouple for direct conversion of heat to electricity . . . a new photomultiplier tube using cesium telluride . . . another photomultiplier tube containing a cesium-antimony dynode . . . time-and-frequency-standard devices containing cesium . . . and a rubidium magnetometer. Potential uses for the elements include fuel for ion rocket engines . . . catalysts . . . heat-transfer systems . . . piezoelectric instruments, organic-synthesis intermediates . . . and in storage batteries.

Engelhard opens lab

Engelhard Industries, Inc., recently opened a new laboratory in Newark, N. J., that will be the headquarters of research and development for the entire corporation.

Composed of 15 domestic divisions, plus several foreign subsidiaries, Engelhard Industries, Inc., is primarily engaged in the extraction, refining, and fabrication of precious metals. Projects of the new laboratory include studies of the properties and refining of platinum metals and their alloys . . . the effect of platinum metal catalysts on organic compounds . . . the use of platinum metals in petroleum chemistry . . . the surface conditioning of metals . . . electroplating of platinum metals . . . electron microscopy . . . and spectroscopy.

Engelhard-Imperial pact

Marking the second agreement between Imperial Chemical Industries Ltd. and a major American firm in recent weeks is the announced pact with Engelhard Industries Inc. covering the production and sale of platinum-titanium electrodes. Engelhard will commence production of platinized-titanium electrodes similar to those of ICI's Metals div. Advantage of these electrodes for the production of materials such as chlorine will lead, it is claimed, to increased operating efficiency. Research is currently being conducted in the use of these electrodes in electrodialysis, the conversion of sea water to drinking water, electro-descaling, and electrod-reduction. The pact also covers exchange of information and establishment of joint projects by the research and development facilities of the two firms.

High-temp castable alloy made

Developement of a die castable metal alloy for use at temperatures above 500°F. has been announced by Dow Chemical Co.

Called HM11XA, the alloy is the fourth member of Dow's magnesium-thorium group, and contains approx 1 pct Th, 1 pct Mn, and the balance magnesium. It is reported that the new alloy retains good mechanical properties through 800°F.

Structure beryllium sheet

The world's first fabricated beryllium structure has been developed by engineers at the Martin Co. Their fabrication of beryllium into a basic airframe structure will make it possible to solve many of the aerodynamic and structural heating problems associated with space flight and re-entry of the earth's atmosphere.

Development and fabrication was performed in conjunction with Nuclear Metals, Inc., Concord, Mass. An Air Force contract let to Martin in 1957 led to the development.

The problem of brittleness in beryllium forms was met by attempting to control both the crystal size and orientation during basic sheet fabrication.

Limitations on beryllium's usage still remain, however, engineers point out. Forming or bending the sheet can only be performed within a finely defined band of hot forming temperatures, they note. Presently, the sheet can be joined only with fasteners, and cannot be fusion welded.

Alcoa enters UK picture

Imperial Aluminium Company, Ltd., is the product of a merger between the Aluminum Company of America and Britain's Imperial Chemical Industries, Ltd. (ICI).

Alcoa and Imperial Aluminum Company, Ltd., plan to establish this new aluminum fabricating concern "to accelerate the already rapid growth of aluminum manufacture and applications, particularly in the UK and British Commonwealth markets."

Under the agreement, Imperial Chemical Industries will own 51 pct of the company, and Alcoa 49 pct.

Plans call for the newly-established company to operate ICI's expanded and modernized aluminum rolling mill and extrusion plant at Waunarlywed, near Swansea, South Wales. Originally built for the British Government during World War II, ICI bought the plant after the war.

JUST PUBLISHED . . .

"ECONOMICS of the MINERAL INDUSTRIES"

- **Foreword by the Honorable Herbert Hoover**
- **Edited by Edward H. Robie, former Secretary of AIME**
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Here is the first book to be released for many years on Mineral Economics. It is the most comprehensive volume ever published on the subject . . . expertly written and edited by top men in the field, as a memorial to Harvey S. Mudd. For everyone active in any phase of the mineral industries, it will be an invaluable reference source. Young men just starting their careers in geology, mining, metallurgy, or petroleum will find it an ideal means of broadening their knowledge and preparing for added job responsibilities.

Of equal importance, "Economics of the Mineral Industries" will be valuable to experienced engineers and executives to help them keep in touch with the latest in methods and practices. In fact, everyone who has any relation with the mineral industries will find something of direct interest in some of the chapters.

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18. Minerals in Man's Future, by Zay Jeffries.

The price of "Economics of the Mineral Industries" (770 pages) is $10.00, less a 30% discount to members of AIME. (Extra postage to nonmembers outside of the United States, 50 cents per copy.)

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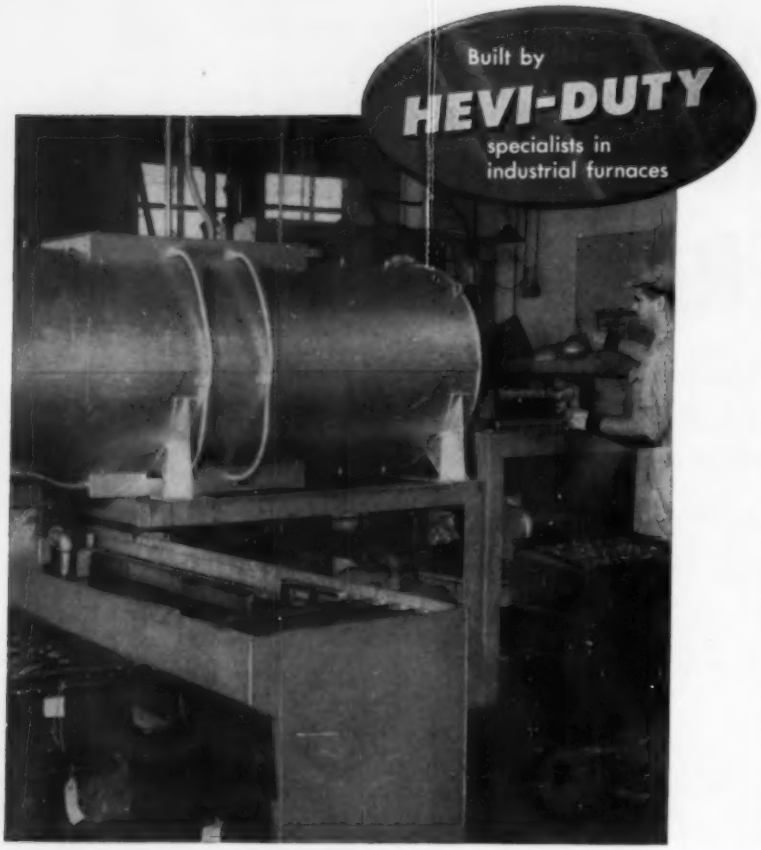

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This is the kind of performance Fred Heinzelman & Sons, New York's oldest heat treat shop, likes to talk about. Carl Heinzelman says, "We like the operating simplicity of our Hevi-Duty Shaker Hearth Furnace as well as its excellent temperature uniformity. The uniform quality of the work it turns out has eliminated rejects."

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Parts processed in this furnace are springs, washers and screw machine parts. They are treated under protective atmosphere at temperatures varying from 1450° F. to 1850° F. and quenched in oil. All parts come out at maximum hardness for each metal.

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BOOKS

(Continued from page 490)

register of manufacturers, and an index of catch words (in four languages). Produktenboek may be obtained free of charge by writting to the Association of Metalworking Industries, 13, Nassaulaan, The Hague, Holland.

Marks' Mechanical Engineers' Handbook, 6th edition, edited by T. Baumeister, McGraw-Hill Book Co. Inc., New York, 2270 pp., $23.50, 1958—This edition of the handbook reflects many changes and developments in the engineering field. Every branch of mechanical engineering is covered—from aeronautics to mechanical refrigeration, from metal-cutting machines to electrical engineering and strength of materials, with a collection of concise descriptions, fundamentals, formulas, methods, tables, and diagrams. Included are more than 2000 illustrations. •

Modern Foundry Practice, edited by E. D. Howard, Philosophical Library Inc., New York, 464 pp., $15.00, 1959—Each of the 13 chapters in this guide has been written by a specialist. The result is an ideal handbook for apprentices, students, craftsmen, and executives. The text of this third edition has been thoroughly revised and enlarged. Chapters include subjects such as ferrous metals, non-ferrous alloys, moulds and mould-making, melting furnaces, and fettling practice. A new feature of this edition is an appendix on inspection of castings and foundry-work training. •

Semiconductors, edited by N. B. Hannay, Reinhold Publishing Corp., New York, 767 pp., $15.00, 1959—Placing emphasis on basic principles and phenomena, each chapter is preceded by an introduction that places the material in its proper perspective with semiconducting as a whole. Contributors are leaders in semiconductor research, and are well known in their particular fields. Chemical aspects and the physics of semiconductor behavior are treated at great length. •

Semiconductor Abstracts, vol. IV, 1956 issue, edited by E. Paskell, John Wiley & Sons Inc., New York, 456 pp., $12.00, 1959—Prepared by the Battelle Memorial Institute and sponsored by the Electrochemical Society Inc., this reference guide contains 1462 abstracts of papers concerning the semiconductor field—including papers presented at meetings of the American Physical Society and the Electrochemical Society. A table of contents, cross-referenced subject index, and author index are provided.

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H. H. Kellogg, Jr.

EDITORIAL

Where did you go?

To work.

What did you do?

Nothing.

Ever answer questions like that, figuring it wasn't worth the trouble to give an answer that would not be understood anyway? If you have, then consider the following:

Question 1. How long has it been since *you* broke an axle or a spring in your car?

Questin 2. What consumer goods will be made of precipitation-hardened stainless steel?

Question 3. What applications will be found for the superstrength *whiskers* that are now little more than a laboratory curiosity?

The questions get progressively harder to answer—but this is not the point. The conclusion that may be drawn is that metallurgical research has, is presently, and will continue to provide materials that will vastly improve articles of everyday use—and make possible many not even thought of today.

There is perhaps a tendency among those working in metallurgical research—dealing as it does with high temperature properties, exotic alloy systems, and the like—to feel far removed from the creation of new consumer products that achieve wide public recognition. There is no doubt that the proverbial "John Q. Public" would find little in the TRANSACTIONS within his interest or understanding. However, it should not be forgotten that this same person drives an automobile that is a monument to metallurgical research, carries a tiny transistor radio in his pocket, a metallurgical development only 10 years old, and comes into contact with new applications of metals and alloys every day. The coming years are bound to provide more spectacular developments: silicon-iron magnetic alloys should reduce the size of motors and electrical equipment just as the transistor is doing in electronics, and thermoelectric devices hold promise of revolutionizing all heating and refrigerating equipment.

It is important for us to remember that all of these developments—those cited above and many, many more—create a feeling of public recognition and esteem that is essential to the existence of any profession. An extreme example of this occurs periodically in the medical profession; development of something like the Salk vaccine brings not only fame to its inventor, but also gives a large boost to the entire medical profession, for such a development is one in which the entire profession may be justly proud. So too in metallurgy . . . As new materials and devices become available for industrial use, defense, or to the general public, the entire profession should take pride in the accomplishment. For without pride, there is no profession.

J. J. Burke

METALLURGISTS

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education

N.Y.U. Holds Vacuum Metallurgy Symposium

More than 200 scientists and engineers gathered at the University Heights campus of New York University early in June for the third annual Vacuum Metallurgy Symposium.

Perhaps most significant in this year's program was the number of papers devoted to advances and applications of electron beam melting. Hugh R. Smith, Jr., Temescal Metallurgical Corp., one of the developers of the process, returned to this year's conference with both new techniques of operation and new applications. New, higher-powered electron guns in various configurations have been developed for attaining more efficient melting operation. Several versions of *distant* cathodes—in which the cathode is placed far enough away from the melt stock that its efficiency is not impaired by metal splatter—have been used successfully. Mr. Smith pointed out that close tolerances must be observed with such cathodes in order to satisfy the electron optics. He also noted that some difficulties have been encountered in focusing, due to space charge limitations in obtaining large power densities at reasonable voltages.

In the past year, experience with several metals and alloys normally considered brittle in the as-cast conditions has shown that the very low impurity levels obtainable in electron melting will greatly increased room temperature ductility. Tungsten, molybdenum, columbium, hafnium, and tantalum have shown such improved properties that they are now finding application in purposes formerly considered impossible due to difficulties in fabrication.

W. R. Witzke, Lewis Research Center, NASA, reported on experiments in purification of tungsten by electron bombardment floating zone melting. Tungsten rods up to 3/16 in. diam. have been successfully refined in this manner; for example, impurities such as oxygen dropped from 140 to 4 ppm. It is felt that evaporation, rather than the zoning action, is responsible for the removal of impurities.

Room temperature bend tests showed a considerably greater ductility for zone-melted rod than for swaged commercial rod. X-ray diffraction and chemical etching of several rods showed that they were single crystals, but it is not known at this time whether the increased ductility results from the purification achieved by zone melting, the fact that the zone-melted rod is a single crystal, or a combination of the two. However, working of the zone-melted rods by swaging and rolling has been accomplished at tempera tures as low as 1600° and 900° respectively.

Work done on electron beam melting of beryllium by Lockheed's Missiles and Space div. was also reported, but preliminary results showed no notable improvement in properties. Work done on this most promising of metals is also continuing at Temescal.

A special feature of the Symposium was a talk by W. H. Steurer, formerly head of the materials division of the Army's ballistic missiles agency at Redstone, Ala., and now with Convair in San Diego. His subject was *Effect of Space Environment on the Properties of Materials.*

Mr. Steurer said that space environment, from the viewpoint of its effects on materials, may be divided into four components: vacuum—density and pressure; thermal environment—radiant and aerodynamic heating; radiation—solar and cosmic; and meteoric particles— meteorids and cosmic dust.

"It is presently impossible to appraise all potential combinations of environmental influences and to derive accurate criteria for the selection of materials in space vehicles. In addition to the environmental criteria, operational, as well as design and technological requirements, may be of equal importance in the selection of materials, since these criteria may differ substantially from conventional concepts. On the basis of the limited theoretical and experimental information it can, however, be concluded that the peculiar characteristics of space environment do not so much call for the development of entirely new materials, as for a readiness to accept unconventional criteria in the selection of known materials and designs." Proceedings of the conference, edited by Prof. R. F. Bunshah of N.Y.U., will be published by the Rheinhold Publishing Co. at a later date.

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■ Pioneering work in metallographic research, high and low temperature materials, radioactive and toxic materials, pure metals, properties of beryllium and the alloys, and the development of refractory and special-purpose metals, cermets and ceramics is being done at Lockheed Missiles and Space Division.

Main objectives of the studies are to evaluate the chemical, physical, and mechanical properties of metals and ceramics, and to study the effect of external conditions of stress, temperature, and strain rate on the materials, as well as the effect of alloy additions, impurities and past strain histories.

Preliminary studies are also being made in: transpiration-cooled and heat-resistant rocket nozzle material systems; thermionic-emission converter materials; solid-state devices for electronic application; electro-chemical fuel cell systems; substrates and films for the micro-miniaturization of electronic systems; analysis of fuel and oxidizer tank leakage problems; and materials development for nuclear propulsion reactors.

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TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME

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AISI Meeting Features AIME Members

Four AIME members played featured roles at the American Iron and Steel Institute's meeting in New York during May.

F. M. Rich, vice president responsible for steel manufacturing, Inland Steel Co.; J. S. McMahan, supt. of blast furnaces, The Steel Company of Canada, Ltd.; and A. F. Franz, president of The Colorado Fuel & Iron Corp., gave principal addresses during the two-day meeting.

Speaking on *Steelmaking in the Soviet Union*, Mr. Rich said that, "the Russian steel industry is like one big company. The Soviet state has power to manipulate wages, prices, production, and distribution without regard for consumer need." He based his statement on his experiences while a member of the Amercian steel and iron ore mining delegation that visited the Soviet Union last year.

In his paper on *Experience with Self-Fluxing Sinter at the Steel Company of Canada, Ltd.*, Mr. McMahan noted that "The daily iron production of a blast furnace was increased from 653 to 1073 tons by replacing natural iron ore with sinter."

Attacking the subject: *The Big Squeeze on Little Steel*, Mr. Franz explained that "A realistic tax policy should be adopted that will permit us to recover the purchasing power of our original investment. This can then be reinvested in modern equipment which will help to reduce costs of production."

In other ceremonies, John D. Saussaman, asst. general supt. of the iron and steel div., Kaiser Steel Corp., won the Institute's Regional Technical Meeting Award in the field of operations for his paper on the *Effect of Ore Beneficiation on Blast Furnace Operation*, given in San Francisco last November.

PERSONALS

(Continued from page 488)

Arnulf Muan, associate prof. of metallurgy, Pennsylvania State University, attended the International Symposium on the Physical Chemistry of Process Metallurgy in Pittsburgh, Apr. 27-30. The Symposium dealt with nonferrous extractive metallurgy, hydrometallurgy, and the application of physical chemistry principles to commercial processes.

John D. Sullivan, member of the Board of Trustees of The Metallurgical Society, AIME, was recently awarded an honorary lifetime membership in the American Ceramic Society. Dr. Sullivan is the 16th American in the entire Society's history to receive such an honor. "He had a key role in the earliest Battelle studies," says the *Battelle Technical Review* in recounting his contributions to ceramics which lead to the award. He has been associated with inquiries into the surface chemistry of clays, development of refractories, examination of the nature of expanded aggregates, exploration of methods for enameling copper, and other subjects.

Since 1945, Dr. Sullivan has been Technical Director at the Battelle Memorial Institute in Columbus, Ohio. During World War II he has cited for his work with the War and Navy Departments. Dr. Sullivan headed the Processes Research div. of the War Metallurgy Committee and undertook other research work in the war effort.

James H. Kelley has been appointed supt. of the Open-Hearth div. at the Sparrows Point plant of Bethlehem Steel Co. In 1952, Mr. Kelley received the Gary Medal of the American Iron and Steel Institute for developing the use of coke-oven gas in the open hearth.

Announcement was also made of **Russell R. Jones'** appointment to the post of asst. supt. of the div.

In other action, **Bernard E. Hoffner** was named asst. supt. of the Coke-Oven dept.

E. B. Speer has been named vice president in charge of operations at U.S. Steel Corp. Affiliated with U. S. Steel since 1938, Mr. Speer was promoted from his position as general manager of steel operations.

C. M White was elected a vice president of the American Iron and Steel Institute at its Sixty-seventh General Meeting in New York recently. Mr. White is Chairman of the Board at Republic Steel Corp.

Gregg M. Moga is a newly elected vice president of Strategic Materials Corp. of Buffalo. In his new position Mr. Moga will work for both Strategic and the Koppers Company, Inc. He will be a sales representative responsible for developing potential applications for the Strategic-Udy Smelting-Refining Process.

David Knall is vice president in charge of engineering and construction at the Henry J. Kaiser Co., Oakland, Calif. Mr. Knall was formerly blast furnace engineer at U.S. Pipe & Foundry Co., Birmingham, Ala.

R. K. Hopkins was recently made vice president in charge of specialty alloy steel operations at Firth Sterling Inc., Pittsburgh. The operations were formerly owned by M. W. Kellogg Co., and prior to his election to Firth's board of directors, Mr. Hopkins was associated with the Kellogg Co.

John T. Whiting, chairman of Alan Wood Steel Co., was named an honorary vice president of the American Iron and Steel Institute at its recent New York Meeting.

Leo F. Reinartz was granted an Honorary Doctorate degree from Capital University at exercises in Columbus, Ohio, June 1st. Mr. Reinartz, a consultant with the Armo Steel Corp., Middletown, Ohio, was recognized for his contributions to education and engineering. His series on the history of steelmaking in the US appeared in JOURNAL OF METALS.

James A. Burka, formerly of the research staff, University of Kentucky, has been appointed to the staff of the Oak Ridge National Laboratory. The atomic energy installation is operated by Union Carbide Nuclear Co., div. of Union Carbide Corp.

Bani R. Banerjee is now supervisor of the Applied Physics Section of the Central Research Laboratory. Crucible Steel Co., Pittsburgh. Formerly, Dr. Banerjee was senior project physicist of the Research and Development dept., Standard Oil Co., Whiting, Ind. While in Indiana, Dr. Banerjee headed the Curriculum Committee of a Science-Seminar Program in Gary. The program provided an accelerated presentation of science for a select group of high school seniors there.

Malcom F. Judkins has been named technical director of commercial production engineering at the Sylvania Corning Nuclear Corp., Hicksville, N.Y., plant. Formerly with the Westinghouse Atomic Power div. at Los Alamos and other A.E.C. organizations, Mr. Judkins was more recently associated with Firth Sterling, Inc., as director of their new product development.

Kenneth E. Lewis is the new process control manager of the Stainless and Strip div., Jones & Laughlin Steel Corp., Detroit. He was formerly manager of quality and process control for the Division's Detroit and Louisville plants.

Charles W. Schuck has been promoted to vice president in charge of manufacturing at Braeburn Alloy Steel Corp., subsidiary of Copper & Steel Industries, Inc. With Braeburn for 19 years, Mr. Schuck was formerly supt. of production.

Schrade F. Radtke, the Lead Industries Association's new research director, was one of the hosts at a meeting of the Association in Chicago May 19th. Dr. Radtke was formerly the director of metallurgical research laboratories, Reynolds Metals Co.

Robert L. Ziegfeld, secretary of the Lead Industries Association, headed the meeting which brought together the nine university professors currently doing research on glass and ceramics under Association fellowships.

TRANSISTORS . . .

Their Industrial Impact

Today the development of transistors stands on the threshhold of maturity. From basic industrial research it has grown into a multi-million dollar industry that completely pervades our economy in just 10 years. Following is an outline of this historical development, and a glimpse into what the future holds.

by J. A. Morton

THE story of the transistor has been the struggle to translate solid-state scientific potentialities of high performance . . . high reliability . . . and low cost into practical reality.

The era from announcement of the invention of the point-contact transistor in mid 1948 to mid 1951 can be likened to early childhood. Key items in advancing the device technology and research understanding came through the development of pulling and zone melting methods for growing single crystals of germanium of unprecedented purity and crystalline uniformity.

Research work resulted in theoretical prediction and physical realization of the junction transistor with greatly improved performance. Fabrication of junction diodes, triodes, and phototransistors was accomplished both by growing and alloying techniques. The micropower, high gain, and low noise predicted for such devices was proved.

Mid 1951 to mid 1952 represents a period of adolescence when gains in performance encouraged further applications. However, new reliability difficulties were brought to light. These reliability problems were shown to be surface dependent, and research and development programs on surface physics and chemistry were initiated throughout the industry. This heralded the *young manhood* period of 1952 to mid 1955.

Larger responsibilities and definite commitments were undertaken. For example, point transistors went to work in an operator tone dialing trial in October 1952. The first over-the-counter sales of alloy and grown-junction transistor hearing aids took place about the end of 1952. A few years later no manufacturer produced tube hearing aids.

In March 1953, point-contact phototransistors and transistors were employed in the card translator portion of direct distance-dialing equipment. Tradic, the first transistorized military computer, was demonstrated in January 1954, and, later in the same year, the first all-transistor personal radio became available in time for the Christmas market. Other equipment developed during this era included the first all-transistor industrial computer, and transistorized telephone sets for the hard of hearing and for use in noisy locations.

On the military side, digital data transmission and processing systems, computers, and missile control systems relied wholly or in part on transistors for their successful development and trial.

This sudden expansion in applications called for a wide variety of transistor types. Techniques for germanium were pushed to their limits, and germanium crystals of almost perfect physical and chemical properties were developed to improve manufacturing yields.

Diodes, triodes, tetrodes, and a wide variety of power units were developed and put into manufacture. Silicon entered the field as an alloy junction diode of greatly improved properties.

Gains in understanding of the physical-chemical surface effects in reliability were made through improved surface treatment and capsulation techniques. Reliability surpassed that of all but the best telephone tubes. In fact, one hearing aid transistor manufacturer complained bitterly and frequently about the disappearance of his replacement business.

The wide variety of applications called for a staggering range of characteristics. Point, grown, alloy, and surface barrier techniques on germanium and silicon were close to their capability limits. However, each structure and technique had serious limitations. Transistor designers and manufacturers were forced to develop about 200 compromise designs, thereby creating a manufacturer's nightmare which inhibited large-scale economical manufacturing of any one prototype. This was reflected in high costs—from $2.00 to $45 per transistor.

Meanwhile, research people were busy pushing ahead frontiers of basic understanding in materials, structures, and techniques. In 1954 they made a triple breakthrough of such magnitude that it brought an end to the period of young manhood and

J. A. MORTON is vice president of Bell Telephone Laboratories, Murray Hill, N. J.

This paper was originally presented at the symposium on Government-sponsored Research on Semiconductor Metallurgy, sponsored by the IMD Semiconductors Committee during the 1958 Fall Meeting. The same committee is sponsoring a technical conference on "Properties of Elemental and Compound Semiconductors", to be held in Boston from Aug. 31 to Sept. 2. The complete Conference Program appears in the July issue on page 475.

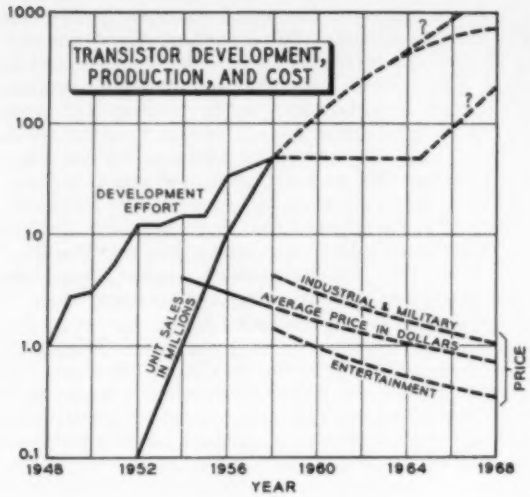

Fig. 1.

began a new era—the *Era of Maturity*. This work demonstrated the possibility of removing most of the limitations which forced design compromises into a multiplicity of techniques.

By proving the feasibility of purifying silicon to transistor requirements . . . solving the problems of solid state diffusion as a technique . . . and by devising the diffused base structure, they demonstrated the possibility of making diffused silicon transistors with cutoff frequencies of 50 to 100 megacycles per sec (5 to 10 times faster than the older germanium transistors), while at the same time retaining the silicon advantages of high power, temperature, and efficiency. Application of similar structures and techniques to germanium pushed the frequency frontier into the low microwave region.

The magnitude of these research accomplishments dictated a re-evaluation of most transistor development programs, which began in mid 1955. It was realized that further refinements of growing, alloying, and surface barrier techniques were possible, but only at large development and manufacturing costs. However, the dramatic demonstrations of the potentiality of these new diffusion techniques, based as they were on more complete scientific understanding, clearly showed that maximum effort should be devoted to their development. The eventual economies of a single prototype diffusion technique and diffused structure, with heavy emphasis on silicon, were the goals.

Present status

Where has this diffusion breakthrough brought us today? In production or just entering production are the following diffused devices:

1) Silicon power rectifiers ranging from 0.5 amp to 100 amp which will handle reverse breakdown voltages up to thousands of volts;
2) Silicon voltage limiters with closely controlled breakdown voltages ranging from 4.2 v to 200 v;
3) Diffused base silicon transistors with frequency cutoffs in the 50 to 100 megacycles per sec range. As switching transistors, they will provide 10 megacycles per sec switching rates with attendant power dissipation up to ¼ w;
4) Diffused base germanium transistors with frequency cutoffs as high as 1000 megacycles per sec. One code of this prototype designed as an oscillator has a minimum rating of 50 milliwatts output power at 250 megacycles per sec. Other codes designed for very high speed switching provide switching rates as high as 50 to 100 megacycles per sec.

Today, the circuit designer has a broad range of performance characteristics at his command. These new devices greatly extend the range of performance formerly possible. For instance, the power and frequency range has been extended 10 to 100 times by the application of the new diffusion science to silicon and germanium. The availability of such a complete performance range has profoundly affected the kinds and numbers of system applications.

In transmission systems: pulse code modulation carrier, personal radio paging, and vhf communications depend upon diffused germanium devices. Although transistors have not yet found their way into commercial television receivers, laboratory developments indicate it to be highly probable—with attendant savings in size, power, and maintenance costs.

In power systems: the new diffused silicon rectifiers, voltage regulators, and lightning protectors are essential components for success.

In electronic switching: the new diffused diodes and triodes used in computers and digital data processing equipment are greatly extending speeds and reliability, while at the same time greatly reducing the size and power required for such large and complex machines.

In the military area: too, this new line of devices is gaining acceptance in computers, missile systems, servo-systems, fuses, radar, communications and power supplies. In fact, diffused germanium transistors are now circling the earth in the EXPLORER and VANGUARD satellites and leaving the earth in PIONEER.

All in all, today's class of new and old transistors is finding its way into a staggering variety of tube replacement and non-tube equipment. To round out the list, binaural hearing aids . . . portable radios . . . phonographs and dictating machines . . . auto radios and fuel injection systems . . . portable cameras . . . paging receivers and instruments . . . machine tool controls . . . clocks and watches . . . toys . . . and even a guidance system for a chicken feeding cart should be mentioned.

Presently, there are approximately 70 domestic and foreign manufacturers of transistors and related diodes. Production figures abroad are not available, but it is known that nearly every major Western nation, as well as Japan, is very active. It is believed, however, that they are somewhat behind the US in development and production. We have no authoritative technical information on Russia's status, but *Pravda* assures us that the USSR is well in the forefront—as usual??

New designs

In the laboratory stage there are a number of new designs which will extend, even further, the range of electrical performance of devices presently in manufacture. One is the four-region pnpn silicon switching diode. The electrical characteristics of this device are similar to those of a cold cathode gas tube. However, the silicon device requires a great

deal less power and can operate at speeds 1000 times faster than the gas tube. Thousands of these diodes will be used in the switching network of all-electronic telephone systems. Other major applications will doubtless be found in military and commercial digital computers.

This small device illustrates beautifully the need for a technology based on the sciences of chemistry and metallurgy. It is necessary to accurately control the density of known chemical and physical imperfections throughout the bulk material. It is also necessary to control the type of imperfections (the energy level within the forbidden gap). On the surface one must control and add impurities in such a manner that the density and type of surface states are within reasonably narrow limits so that the device will be electrically stable over long periods of time. Recent developments have made such precise control of each of these properties possible.

With the ever-advancing speeds of electronic computers come requirements for faster and faster computing diodes. By a controlled chemical reduction of minority carrier lifetime, storage and recovery times have been reduced to less than 2 millimicroseconds. These designs will extend the speed of computer diodes by a factor of 10.

New diffused transistor structures are being made in the laboratory by reducing the important geometrical dimensions to the order of microns. In this way the frequency range of germanium and silicon transistors can be extended by another factor of 10 over the present designs. It is expected that diffused germanium transistors will soon be made which will oscillate at frequencies as high as 10,000 megacycles per sec.

The future

Unlike the short term extrapolation of known principles, it is difficult and perhaps impossible to predict the long-term future in fields in which there has been and is apt to be frequent and important research breakthroughs. Such discoveries of knowledge and invention cause the subsequent technology to progress in a series of jumps, large compared to the relatively slow growth between such steps. The unpredictability of these steps in detail and time make such long-term forecasts only qualitative at best.

How can one estimate future progress in a field in which advances may depend so much upon new scientific knowledge and invention? One way is to examine the pattern of progress in the past 10 years and to use this in predicting the future.

Because the field is diverse and based upon a rapidly growing foundation of organized scientific knowledge, the interrelationship between research and its development into an industrial technology has been unusually close. This close and sensitive interrelationship, as it has existed within the Bell Laboratories, has resulted in a development effort which has responded quickly to research accomplishments. The relative amount of development dollars spent in converting research into technology is perhaps one good measurement of research impact. Fig. 1 shows the relative yearly cost of transistor development in the Bell Laboratories from 1948 to 1958. During this period it grew by a factor of 40, whereas the total Laboratories' development budget slightly more than doubled in the same decade.

Can we correlate these curves with known research achievements? The first sharp rise from zero in 1947 to the reference value of 1.0 in 1948 and to about 1.3 in 1949, was the technological response to the basic invention and the development of single crystal growing techniques. The rise from 1.3 to 10, from 1950 to 1952, was the response to the theoretical prediction and experimental proof of junction transistor principles. This period was also stimulated by zone purification of germanium and the development of alloy junction techniques. The third rise from 1955 to the present represents an appraisal of the relative and lasting importance of diffusion-silicon research results.

The wide range of functions and applications described earlier provides qualitative measures of the impact of these discoveries, while the transistor production and sales records provide a quantitative measure of the economic impact of these accomplishments, as also shown in Fig. 1.

Today we stand on the threshold of maturity. The major applications to date have been primarily in replacement of electron tube functions because of economic, size, power, or reliability advantages. Few practical inroads have yet been made into the vast and important domains of electronics having to do with control, transmission, and processing of information. Such systems, because of their large and complex digital nature, require thousands and sometimes hundreds of thousands of very fast devices. Until recently such large-scale applications have been limited by the performance, reliability, and cost of the older techniques.

The search for scientific understanding and control of minute imperfections in otherwise perfect crystals of germanium and silicon has been the essence of transistor electronics. Today, with the addition of diffusion-silicon technology, practically all of the aforementioned barriers to *new art* electronics have been removed in principle.

Our body of scientific knowledge is sufficiently complete to all but guarantee that an all-out development effort for the next three to five years should bring about significant advances in reliability and cost. Such advances are paramount to the creation of large, complex electronic systems for military and industrial use.

Let us assume for the moment that no further important research accomplishments come to pass for the next 10 years. What, then, is the outlook for growth? It is my belief that the major accomplishments will be:

a) in development: refining, simplifying, and reducing the number of standard designs required to cover all major applications, both old and new art electronic functions.

b) in manufacturing: introducing mechanization, automation, and more scientific surface process control to reduce cost on a few prototype diffused devices of both germanium and silicon.

c) in applications: developing the new circuit and equipment techniques that will lead to the high-level economical manufacture of large, high-speed, digital systems, such as computers, switching systems, and data transmission and processing systems. It follows that cost reductions will lead to further invasions of the present tube electronics.

Under these conservative assumptions, the combined judgments of industry spokesmen predict a growth in transistor production and a corresponding decrease in unit price as shown in Fig. 1. The total dollar volume for transistors alone is, thus, predicted to be over $500 million by 1968. It is also anticipated that the associated semiconductor diode market, based on the same diffusion technology, will likely exceed that for transistors. Hence, the conservative assumption of no further major research advances still leads to the prediction that the transistor industry will surpass electron tube electonics in the next decade.

However, the techniques developed for the new technology feed back new tools and problems to further stimulate research. All over the world, basic research is continuing at a greater level of activity over a broader front and to a more penetrating depth. It seems, therefore, to be a more likely assumption that continuing important knowledge and inventions will be forthcoming in the next decade. It would be impossible to cover the field because of its tremendous scope. But what are a few of the exciting possibilities; in what area do they lie; and what might be some of their technological effects?

Materials

Germanium and silicon are but two of the literally hundreds of potentially useful semiconductor materials. Being the simplest, they are the most completely understood. Using the basic techniques developed for these two materials, many scientists have been intensively studying a new class of intermetallic compounds which are closely related to germanium and silicon in their structures and electronic properties. While our knowledge is far from complete, recent investigations have shown that we can make a number of such intermetallic compounds with a wider range of electronic properties than is obtainable with germanium and silicon. For example, theory tells us that indium phosphide and gallium arsenide devices should operate to higher temperatures (and/or powers) of the order of 300° to 400°C, and provide still higher frequency and broader bandwidth—all with the structures and techniques of today. Already, good rectifiers have been made of these materials which verify the initial predictions.

Devices

We have just predicted an extension in power-frequency performance to be expected from making present device structures from the new materials mentioned. But it seems likely, but less specific, that new mechanisms of energy interaction within the solid semiconductor may be discovered which will not only extend the performance but broaden the functions of transistors.

In the laboratory, one can already see germanium and silicon p-n junctions being operated as new variable capacitance amplifiers at frequencies of 6000 megacycles per sec. Theory predicts no serious gain limitations down to millimeter wavelengths, with noise much lower than that possible in the best electron tube. Preliminary experiments are also verifying these predictions.

One new effect that may play an important role in both continuous wave and digital electronics is avalanche multiplication and electronic voltage breakdown in a p-n junction. Excess electrons or holes crossing a p-n junction, at sufficiently high reverse voltage, gain excess energy and generate secondary hole-electron pairs to form a densely charged plasma. These breakdown effects are currently used to make voltage regulating devices. Such effects have exceedingly short time constants, on the order of 10^{-11} to 10^{-12} sec. When such effects are confined to a single microscopic region of the crystal, these *microplasmas* have shown an ability to generate microwave energy and may perhaps be adapted to amplification into the millimeter wave range. With such short time constants ($\sim 10^{-12}$ sec), they may provide the switching devices for 100 to 1000 megacycle per sec computing speeds.

Techniques

Finally, we come to the techniques whereby all such new devices must be fabricated. It is almost axiomatic that the more scientifically such techniques are based, the more versatile, precise, and economic becomes the technology. Diffusion is a unique example of the precision and economy that can be obtained when a technology is scientifically understood. In fact, diffusion has stood for four years without a new and better technique appearing in the laboratory. We believe it will continue to be even more widely used and stand supreme for the foreseeable future, especially since it is readily adaptable to the newer difficult intermetallic compounds.

However, the protection of the semiconductor surface to obtain the intrinsic reliability of the bulk semiconductor is one of the most expensive parts of manufacture. Moreover, present methods are costly because of this lack of basic understanding. With the powerful tools and scientific challenge now appearing in surface physics and chemistry, the way is open for research to develop, within the next decade, the same kind of understanding of surface behavior as the last decade brought for the bulk properties of semiconductors. When this comes to pass, it will make electronic devices even more reliable and less costly.

Summary

Without any major research achievements in the next decade it seems evident that the present reservoir of basic knowledge is sufficiently deep to insure a further major expansion of transistor electronics. But with the basic research achievements that may come, the futue is so broad and diverse as to stagger the imagination. Computers of a speed and complexity 10 to 100 times greater than today's are almost a certainty. With the reliability, cost, and versatile functions promised for the future, we can possibly look forward to electronic systems that can *learn* from their past experience in helping themselves to solve new problems.

Moreover, transistor electronics is but the vigorous leader of the broader field of solid-state electronics to come. Some of the newer knowledge of the physics and metallurgy of ferromagnetic, ferroelectric, electroluminescent, and cryogenic materials is already being developed into new technologically significant devices. We have ample reason to believe that research knowledge is now being generated that will create an even greater solid-state technology than one can see by simple extrapolation of the present.

NEW ENGLAND REGIONAL CONFERENCE

Emphasizes Continuous Casting

Interest and enthusiasm was high at the Thirteenth Annual AIME New England Regional Conference. One of the discussion panelists observed, "This was the largest conference dealing with continuous casting (of nonferrous metals) that has been held in the United States or in Europe."

by Roland P. Carreker, Jr.

THE Thirteenth Annual AIME New England Regional Conference emphasized the E of AIME in its approach and the interests of the New England Region in its theme. The May 21-22 conference was held at the Statler-Hilton Hotel in Hartford, Conn., where 280 registrants gathered to learn more about Melting, Continuous Casting, and Rolling of Aluminum and Copper Alloys.

A half-day session was devoted to each of the general topics: Melting, Continuous Casting, and Rolling. Each session was introduced by a speaker who discussed the principles of the general topic for that session, then followed a specific *state-of-the-art* presentation, and a roundtable discussion by invited experts in the field concluded each session.

Melting

The *Principles of Melting* were outlined by D. R. Hull, of the American Brass Co., who noted that there is no one "best way" of melting, equipment selection and melting practice being governed by a balance of technical, economic, market, and management factors. The importance of gases in molten copper and aluminum alloys was underlined, the H_2, O_2, H_2O balance in particular. Mr. Hull offered the opinion, which appeared later in several different forms, that insufficient attention is given to atmosphere control in the melting of aluminum alloys.

S. C. Burkhalter, of Lindberg Engineering Co., discussed *Fuel Fired Melting Practice* with particular emphasis on aluminum and on the special problems posed by coupling, melting, and continuous casting. In such applications the maintenance of a stable flow of liquid metal of proper composition and temperature is essential, and a 10°F variation in bath temperature is serious.

Induction Melting Practice was reviewed by Manuel Tama, of Ajax Magnathermic Corp., who traced the development and impact of the submerged inductor type of furnace from its introduction in the New England brass industry in 1917 to modern applications in copper, aluminum, and galvanizing.

The *Arc Melting Practice* presentation by J. A. Chandler, Lectromelt div. of McGraw Edison Co., described in detail the three-phase arc melting furnace recently placed in operation by Halstead Metal Products Co. in Zelienople, Pa. This 6-ton capacity furnace continuously melts copper at a rate of 6 tph, using 210 kw-hr per ton at 85 pct power factor. The molten stream is continuously innoculated with phosphorus and feeds a semi-continuous casting machine that produces 7 in. diam x 12 ft long *logs* which are subsequently cut to 12 in. long extrusion billets.

Following these presentations the speakers were challenged in round table discussion by an expert panel consisting of O. B. Atkin, Bridgeport Brass Co.; D. Altenpohl, Aluminum Foils, Inc.; A. E. Beck, U. S. Metals & Refining Co.; R. J. Christine, American Brass Co.; C. R. McNutt, Olin Mathieson Chemical Corp.; and P. H. Kirby, American Brass Co.

Continuous casting

The session on *Continuous Casting* was given an excellent start by J. S. Smart, Jr., of American Smelting & Refining Co., who discussed *Principles of Continuous Casting*. Stressed was the central role of the continuous casting mold as a heat removal device to be fed with molten metal with minimum agitation and minimum velocity. All successful continuous casting processes combine various mold design and mold feeding design features in a highly selective manner to overcome specific problems encountered with any given metal. Idiosyncracies of the various metals are very real and impose limitations on what can be accomplished in the mold.

A. H. Tessmann, of Industrial Research and Development Corp., reviewed *Reciprocating Mold Processes*, citing their evolution from Junghans' work of the early 1930's. Such installations have become the conventional form of continuous casting and have produced large tonnages of steel, copper, brass, and aluminum alloys. They typically take the form of large, expensive installations, 35 to 50 ft high, producing large tonnages of heavy sections. Tessmann described his attempts, in 1952, to cast a small (2 to 3 in. diam) aluminum section in the horizontal plane using such a reciprocating mold. Difficulties with sticking in the mold led to the use of a vacuum chamber on the exit end of the mold, which permitted successful casting. This machine was incorporated into a production line at Southern Electric Co., including horizontal casting, cut-off, bar heating, and rolling to E. C. aluminum wire rod—a line which has operated as long as 400 consecutive hr.

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H. H. Sinason, Lobeck Casting Processes, Inc., was assigned the title *D. C. Billet Process*, but he was quick to distinguish between the direct chill principle and the semi-continuous casting practice and equipment with which it has become synonymous. Such equipment, which has been widely adopted for producing extrusion billets of aluminum and copper alloys, uses a simple, short mold to give shape to the casting and create a shell sufficient to withstand stresses induced by subsequent water spraying. A recent French development, termed the Isomet Process, utilizes a controlled series of steam and water sprays to produce a V-shaped liquid sump in the casting in contrast to the U-shaped sump normally achieved in processes employing the direct-chill principle.

Under the title *Moving Mold Processes*, G. C. Fear, of Aluminium Laboratories, Ltd., reviewed that group of processes in which there is no relative motion between the casting and the mold until solidification is complete. The Hunter-Douglas, the Hazelett Strip-Casting, the Properzi, the Rigamonti, the Rotary Strip-Casting, and the Coors processes all fall in this category. In addition, all of these processes cast relatively thin sections (typically ½ to 1 in.), and all have been used primarily for casting aluminum alloys.

The Continuous Casting Session was concluded by a panel discussion which included R. S. Pratt, Bridgeport Brass Co.; G. Beckmann, Beckmann Engineering Co.; A. E. Beck, U. S. Metals & Refining Co.; R. W. Hazelett, Hazelett Strip-Casting Corp.; F. R. Nichols, Nichols Wire & Aluminum Co.; R. J. Christine, American Brass Co.; J. L. Hunter, Hunter Engineering Co.; and C. R. McNutt, Olin Mathieson Chemical Corp. With this group of acknowledged experts the discussion was naturally lively, pertinent, and specific. The inevitable comparison was made between products made from relatively thin continuous cast stock versus conventional practice. Hunter made the point that the products were different in some respects, sometimes favorably so, citing the absence of pinholing in aluminum foil as an example. He made the further point that, in his opinion, continuous casting was not and would never be the complete answer for sheet and bar shapes but that it could be applied to 90 pct of such production if tailored to each application.

Rolling

W. A. Backofen, Massachusetts Institute of Technology, began the session on Rolling, speaking on *Principles of Rolling*. He used rolling as a specific vehicle to point out the requirements for a really thorough understanding of any mechanical shape changing operation, namely:

1) Material properties and the influence of strain, strain rate, and temperature on those properties;

2) Boundary conditions of the process including the effects of friction and lubrication;

3) The stress-strain distribution in the deformation zone;

4) The resulting dimensions, finish, and properties;

5) Design and performance of the equipment and apparatus to be used; and

6) Costs.

The rolling process has a relatively high shape-changing efficiency in that the work required to produce the change of shape in the material is usually 0.5 to 0.9 of the total applied work. It, like all direct compression operations, is characterized by a friction hill in which the pressure distribution in the deformation zone has a maximum at the plane of zero slip. This friction hill characteristic determines the forming limits of the operation for any particular piece of equipment.

The practical aspects of rolling mill selection and performance from the point of view of a mill builder were covered by G. E. Farrington, E. W. Bliss Co., speaking on *Hot Rolling Mill Equipment*. He, too, stressed the importance of a good forecast of future requirements in selecting an appropriate item of equipment. The factors to be considered by a company expecting an increasing market for its rolled products were discussed. Modern trends cited included: the use of bigger cakes, slabs, or ingots; the use of direct current motors on all mills, separate edgers rather than turning the ingot; higher powered screwdown motors; punched card control of mill openings and auxiliary equipment; coiling by means of tension reel mandrel and belt wrapper; and the use of roller bearings or oil film bearings.

The practical aspects of rolling from a metal producer's viewpoint was presented by G. Signor, Scovill Manufacturing Co., speaking on *Cold Rolling Mill Equipment*. He described a series of mills specifically selected to reduce continuous cast brass slabs (now 28½ in. wide x 3½ in. thick x 5000 lb) at 35,000 lb per hr.

L. E. Thelin, Bristol Brass Co., discussed *Metallurgical Factors in Hot vs. Cold Rolling of Copper Base Alloys*. He made the point that economic as well as metallurgical factors influence the choice of working method. In rolling copper-base alloys the face-centered cubic alloys are amenable to cold rolling, wheras the body-centered cubic alloys such as Muntz metal are hot rolled. In recent years better control of impurities (such as Pb, Bi, Sb) to values below 0.01 pct has made it possible to hot roll many alloys that were formerly cold rolled. In many cases the hot rolling sequence is cheaper since it eleminates many process annealing steps.

The panel discussion on Rolling included P. H. Kirby, American Brass Co.; R. S. Pratt, Bridgeport Brass Co.; D. Altenpohl, Aluminum Foils, Inc.; R. J. Christine, American Brass Co.; and P. R. Sperry, Olin Mathieson Chemical Corp.

Banquet

The conference dinner was sparked by Daniel R. Hull in his capacity as toastmaster and by welcoming remarks from C. C. Long, President-Elect of The Metallurgical Society. The dinner was followed by a most interesting address by Stephen V. Grancsay, Curator of Arms and Armor for the Metropolitan Museum of Art on *Historical Arms and Armor (and their role) in the Development of Metalwork*.

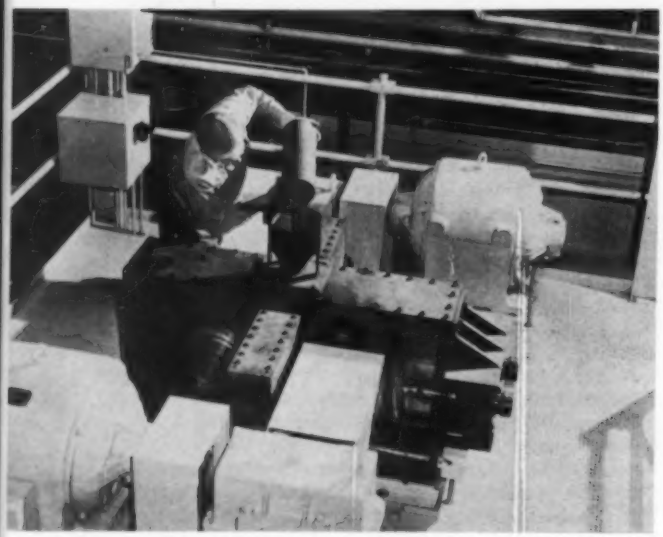
The thirteenth annual conference committee chairman was D. L. Martin who was assisted by D. D. Trout, Past Chairman; J. P. Lynch, Jr., Vice Chairman; C. M. Adams, Jr., Secretary; P. J. Clemm, Jr., Treasurer; R. P. Carreker, Jr., Program Chairman; R. S. Bray, Publicity and Printing Chairman; K. T. Aust, F. S. Chudy, L. Frazier, L. Kaufman, W. P. Matthews, and R. M. Treco.

The following officers were elected to serve for the Fourteenth Annual Conference: J. P. Lynch, Jr., Chairman; D. L. Martin, Past Chairman; C. M. Adams, Jr., Vice Chairman; P. J. Clemm, Jr., Secretary; and F. S. Chudy, Treasurer.

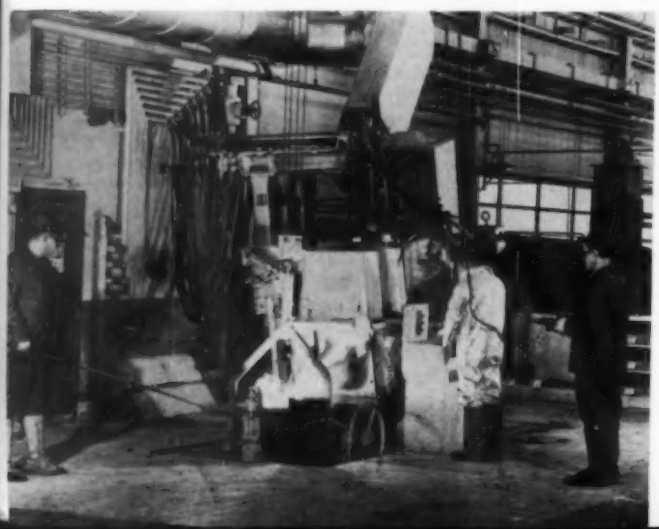
TWO

RESEARCH

Below—A technician pours highly purified and reduced metallic iron powder into a funnel as the second step in Republic's new strip steel rolling process. The powder is compressed into a semi-solid strip by four rolls.



Below—A 1000-lb capacity electric furnace at Republic's new lab is being devoted to studies of refractories, both for service life and effect of various refractory compositions on properties of steels produced.



Republic Shows Direct Stripmaking Technique

Newest scientific laboratory in the steel industry, Republic Steel Corp.'s $5 million research center, was opened on June 18th. The new facility is located on a 106-acre tract in Independence, Ohio, 10 mi south of downtown Cleveland. When the cornerstone of the center was laid in 1957, it was dedicated to Mr. Charles M. White, Chairman of the Board at Republic, in recognition of his long-standing interest in research, especially in new and better processes for producing steel.

Speaking at the dedication ceremonies, Mr. T. F. Patton, president of the Company, said that while Republic had developed its share of new steels and steel products in the past, "steel industry research, to date has only scratched the surface. From ore to finished product, steel technology is undergoing a revolution which is certain to gain momentum in the years ahead."

Describing the type of work to be carried on at the new center, Mr. Patton told those attending the ceremonies that "30 pct of the budget will be applied to research projects designed to show results in one to three years . . . 30 pct to exploratory projects keyed to a five-year schedule, . . . another 30 pct allocated to long-range study projects . . . and 10 pct to pure science—fundamental research projects which have no immediate application . . ."

Mr. Peter Robertson, vice president in charge of research and planning, took the laboratory dedication ceremonies as occasion to announce the successful development of a process for producing strip steel from iron ore, without melting. This process bypasses coke ovens, blast furnaces, open hearths and blooming mills. From the laboratory stage of development, Republic plans a continuous pilot plant line in which larger quantities of materials can be handled.

The process consists of three major steps: First, iron ore is highly purified and reduced to metallic iron powder. Second, it is funnelled between four rolls where it is compressed into a semi-solid strip. Finally, this *green* strip passes through a furnace where it is heated to 2200°F in a reducing atmosphere and passes on through a series of hot strip rolling stands. This reduces the strip to the desired gauge and full density, and produces hot-rolled steel in coils. Mr. Robertson said that these coils have the same quality as conventionally made steels: "We have made steel in the laboratory which offers the same strength, ductility, and ability to be fabricated into finished parts as steel produced by other methods."

It can be expected that this and other new products and processes will be said to have had their origin in this modern and complete research facility.

NEW LABORATORIES

Harbison-Walker Unveils New Aluminum Refractory

June 1959 marked the opening of Harbison-Walker Refractories Co.'s new $2 million research center located outside Pittsburgh. Named after the Company's president, Earl A. Graber, the new laboratory is equipped to carry on all phases of research and development of new refractories, including work on abrasion resistance, permeability, resistance to chemical attack, spalling resistance, thermal expansion, and slag resistance.

Also announced at the opening was the development of a new refractory for use in aluminum production. The refractory practically eliminates the metal's penetration into the furnace lining (see photo).

The research center, meanwhile, is divided into two main buildings, with offices and instrumental research in one and the pilot plant for product development in the other.

Mineral identification laboratories contain petrographic equipment for studies in transmitted and reflected light, emission and X-ray spectrographs for semi-quantitative analyses, and an X-ray diffractometer for crystal or mineral identification. This section also has a well-equipped analytical chemistry laboratory and photographic facilities. Particle size measurement, important in any refractory studies, is accomplished by three methods: two elutriation techniques and one based on surface area. Other specialized equipment measures thermal expansion and thermal conductivity.

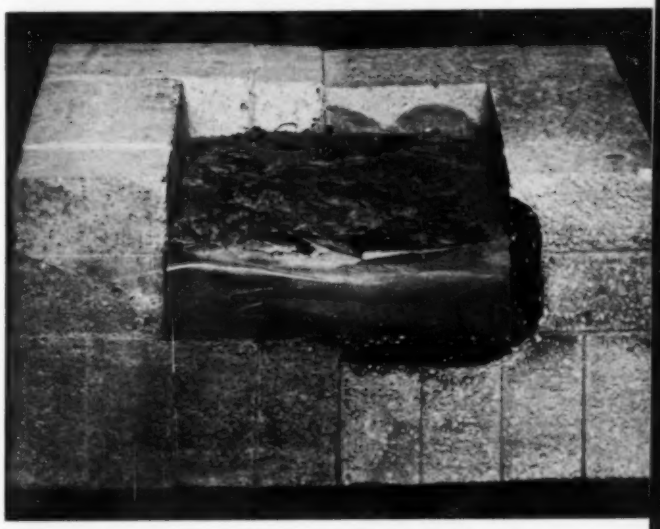
The pilot plant area contains a complete line of crushing, grinding, screening, and mixing equipment. The area complements various forming machines which shape the refractories by pressing, extruding, ramming, gunning, and casting. A 300-ton hydraulic press and a pneumatic impact press are located here, together with drying equipment and an instrumented humidity chamber.

Two kiln areas—one electric and one gas-fired—provide a variety of equipment for testing refractories at elevated temperatures. High-temperature strength, load bearing ability, effect of molten aluminum, and panel spalling are tested here.

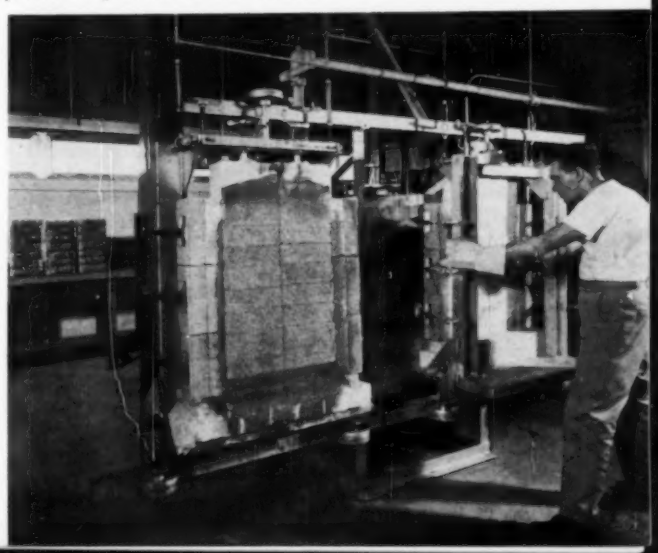
Studies on specialized products such as refractory mortars, castables, and monoliths are carried out in individual laboratories located in this section. Another area has equipment for conducting more routine physical tests: transverse strength, compression testing, abrasion resistance, permeability to furnace gases, density, apparent porosity, and bulk specific gravity.

Other facilities—conference rooms, library, offices—complete the picture of this modern laboratory, which should be responsible for many outstanding developments in the refractory field in years to come.

Below—A dramatic demonstration of Harbison-Walker's new aluminum refractory is shown by the "split hearth". The left side is the new brick, while the right side is made of the best type refractory previously available. Absence of penetration of the molten aluminum—either above or below the metal line—is obvious for the new refractory.



Below—Spalling, a problem in all furnace brick, is here tested at Harbison-Walker's new lab. Two racks of brick are alternately heated—by the furnace on the right—and cooled—by high pressure water sprays on the left. Overhead tracks move the racks from one position to the other.



U. S. STEEL REVEALS PILOT FACILITIES

Consumable-electrode melting
Vacuum stream degassing
Oxygen steelmaking
Direct reduction

OPENING its doors to the outside world for the first time, the pilot plant installation at U.S. Steel Corp.'s South Chicago works revealed future trends of steelmaking as conceived by the Nation's largest steel producer.

Facilities are housed in the same shop where, in 1929, the first stainless steel was made on a commercial basis. The old installations have long since been removed, and the shop has been turned over to the direction of U.S. Steel's Research Center at Monroeville, Pa. Called an "integrated applied research program", work being carried on represents pilot plant testing under steel mill conditions. Emphasizing that the pilot plant operations are not necessarily new innovations, officials point out that the South Chicago project was designed to find optimum means of processing the firm's raw materials to produce the quality steels required in the space age.

Consumable-electrode furnace

Demonstrated was a consumable-electrode vacuum furnace capable of producing up to 32-in. round ingots weighing 20,500 lb. The process yields steels with lower gas content, improved cleanliness, comparative freedom from center porosity and segregation, improved hot workability, and improved mechanical properties at room and elevated temperatures. Experimental work is being done with bearing steels, high-temperature stainless steels, and high-strength alloy steels, although practice work is also being done with carbon grades. Such steels as these, rolled into blooms, form the electrode of the furnace.

The furnace proper consists of two sections: the upper section, a water-cooled tank above ground level that houses the electrode; and the lower section below the ground level, a water-cooled mold in which melting takes place. The furnace is evacuated to 5 μ pressure with a six-stage steam ejector pump. A remote optical viewing system gives the furnace operator a periscopic, continuous view of the arc and molten pool.

(Consumable-electrode furnaces are now employed for the commercial melting of alloy steels at the Watervliet works of Allegheny Ludlum Steel Corp. The story is told in the December 1957 issue of JOURNAL OF METALS.)

Vacuum stream degassing

Also seen was a large-scale vacuum stream degassing unit, designed to cast several ingots at one pouring. The original vacuum unit, built by U.S. Steel at its Duquesne works, has been turned over to commercial operations and is no longer available for experimental work.

With basic similarities to the German vacuum degassing process, described in a JOURNAL OF METALS article in the April 1956 issue, the present unit incorporates a number of new ideas, including a four-stage steam ejector pump capable of evacuating the system to a pressure of 200 μ. Such a pressure is capable of producing steels with hydrogen contents as low as 1 ppm. Another innovation is the turntable on which as many as seven ingot molds can be placed in the vacuum tank. A third new feature is the collector ring within the tank. Molten steel poured into the vacuum tank explodes as the trapped gases expand, but a round, funnel-shaped device, measuring 8-in. in diam at the top and 4-in. in diam at the bottom, keeps the spray of molten metal within bounds.

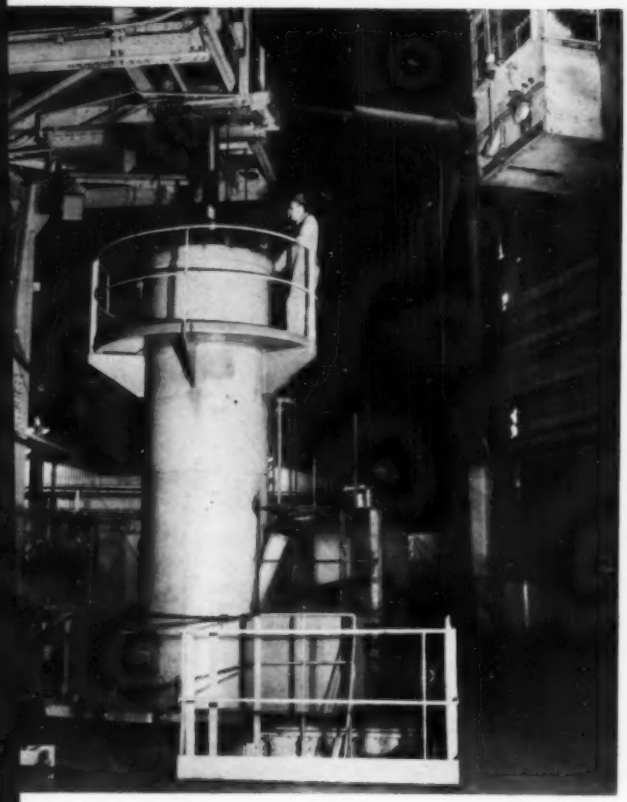
The vacuum casting unit consists of a vacuum tank 16 ft in diam x 14 ft high with a 30-ton ladle placed on top of the tank. Operations are observed by closed-circuit television cameras placed at several strategic locations. With this unit a total of 45 tons of steel can be cast at one time; the vacuum unit capable of being readied for one casting every 9 hr.

Open-hearth and LD

A 1/12 scale model replica of a 300-ton open-hearth furnace used for observing combustion under varying conditions was also shown; no steel is melted in it.

Because of the need for separating combustion effects from the heat generating effects in the chemistry of steelmaking, the furnace was built with a rectangular tank occupying the position of the metal bath. Water flows through this tank and adsorbs heat from the flame. This heat, which can be measured, corresponds to the heat that is absorbed by the metal in a commercial furnace.

The furnace is fitted with a closed-circuit television system in which a water-cooled telescopic



lens is inserted through a port in the end of the furnace. A picture of the furnace interior is shown on a screen on the control panel.

To study the furnace's temperature distribution pattern, the model is equipped with over 20 thermocouples and is fitted with a variety of precision instruments for measurement and control, so that any combustion factor can be varied independently and its effects studied.

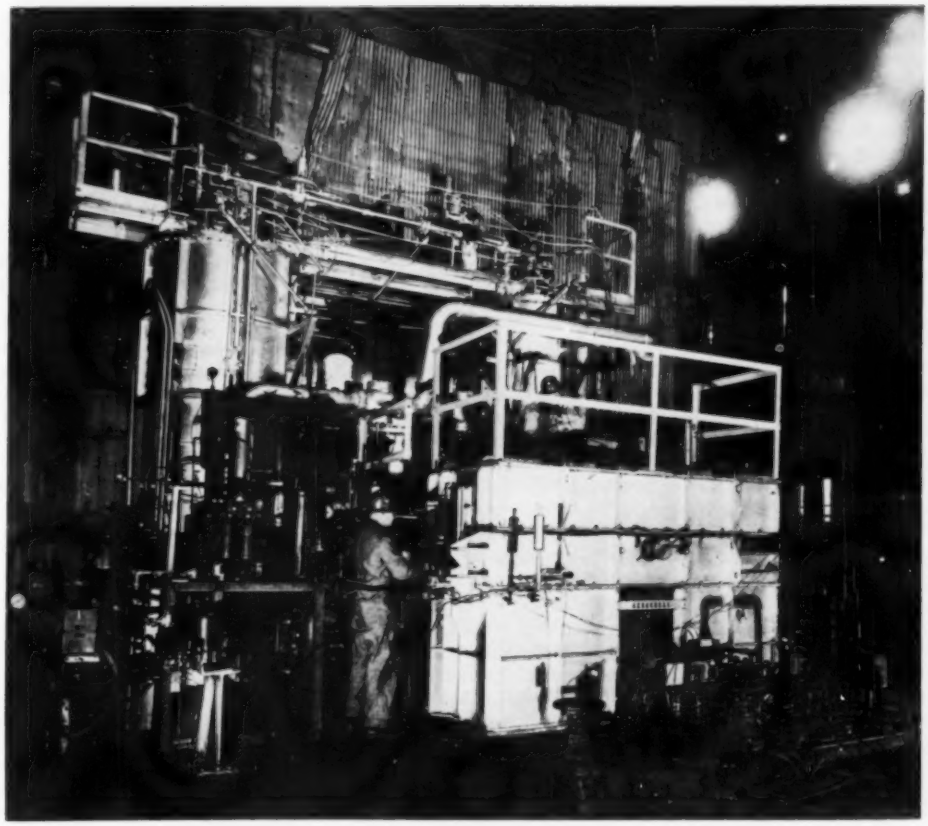
An experimental 8-ton LD furnace that makes use of U.S. Steel's raw materials is being operated to determine operational characteristics.

Direct reduction

Not shown was the direct reduction unit . . . the Nu-Iron process. It is reported that technical tests of the fluidized-bed process have been successful, but under present economic conditions the commercial applications of the process are being put on the shelf. A break-through in methods of hydrogen production resulting in significantly lower cost hydrogen will, no doubt, put the process in quite a different light. Research officials indicate that they are now pursuing other approaches to direct reduction, although their exact nature was not disclosed.

This is definitely not the complete list of experimental operations at South Chicago works, others mentioned only briefly include a process for hot briquetting iron ore and a new oxygen steelmaking process. Perhaps we shall hear more of these in the future.

F. Weston Starratt



Above, the consumable - electrode vacuum melting furnace used in pilot plant operations at U. S. Steel Corp.'s South Works is one of the world's largest. Right, experimental open-hearth furnace is used to study flame characteristics and heat effects.

GRAIN SIZE CONTROL DURING INGOT SOLIDIFICATION

Degree of superheat, nucleation catalysts, and certain solute elements will ultimately give the metallurgist complete control of ingot grain size and shape. The present state of our knowledge is here summarized.

by W. A. Tiller

Grain structure developed during ingot solidification generally determines the degree of chemical heterogeneity, strength, and the strength anisotropy of the ingot. These characteristics greatly influence the workability of the ingot and its final properties.

Three main types of ingot structure are illustrated in Fig. 1. Neglecting a thin *chill* layer at the outer surface of the ingot which consists of equiaxed grains, the main volume of the ingot generally constitutes a zone of long columnar grains and a zone of equiaxed grains, Fig. 1b. In extreme cases, the ingot may be either wholly columnar, Fig. 1a, or wholly equiaxed, Fig. 1c. In practice, one wishes to control the solidification of the ingot to produce either a wholly equiaxed ingot for isotropic properties or a wholly columnar one for anisotropic properties. What determines the ratio of equiaxed zone width to columnar zone width? What determines the size of the grains in these zones? These are the problems to be solved.

Cibula[1] has shown that the presence of certain heterogeneous nuclei in liquid aluminum will lead to the virtual suppression of undercooling in the melt. He found that such melts of aluminum could not be undercooled by more than a fraction of a degree. However, such an effect only changes a coarse structure to a much finer, but still columnar structure. To produce an equiaxed grain structure he found that it was necessary to have an appropriate solute element, like copper, in the melt. He postulated that concentration gradients were produced which hindered the growth of the grains, and concluded that both heterogeneous nuclei and solute elements were necessary prerequisites for a fine-grain equiaxed structure. Let us now see how the heterogeneous nuclei interact with the concentration gradients and the thermal properties of the alloy to produce the various grain structures.

Nucleation catalysts

Before considering the freezing of an ingot, some understanding of heterogeneous nuclei is mandatory. Heterogeneous nuclei, or catalysts, are small particles of insoluble impurity in the melt which may or may not have been added intentionally. At some degree of undercooling of the melt, a certain type of catalyst will be beneficial for the nucleation of the solid phase, i.e. a particle of solid can form more readily on the surface of the catalyst than in the homogeneous liquid. It is found that homogeneous nucleation in the liquid may require undercoolings as large as 250°C,[2] whereas heterogeneous nucleation can occur at undercoolings as small as 0.1°C.[3] For particular catalysts the rate of nucleation vs undercooling will be as illustrated in Fig. 2; a high nucleation rate for a specified catalyst will occur at a critical undercooling, δT_c. Since an appreciable nucleation rate occurs over a temperature range of only a few degrees, a particular catalyst may be characterized by the undercooling at which it produces a high nucleation rate. This nucleation rate, N also depends upon the number of these catalytic particles, N_s, per unit volume of the melt in the following way:

$$N = N_s e^{-\frac{A}{\delta T^2}} \qquad [1]$$

where A is a constant for the particular catalyst. If there are several different catalysts present in the same melt, only the one which has the smallest δT_c will catalyze the nucleation—since the melt will never undercool more than that necessary for the first catalyst to operate.

We do not know, in any rigorous way, how to go about producing a catalyst with a small δT_c. If the

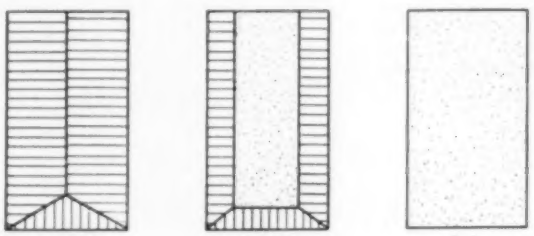


Fig. 1—Three main types of ingot structure.

W. A. TILLER is with the Metallurgy Dept. of Westinghouse Research Laboratories, Pittsburgh.

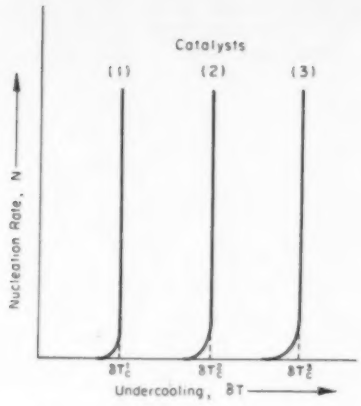


Fig. 2—Nucleation characteristics of three catalysts.

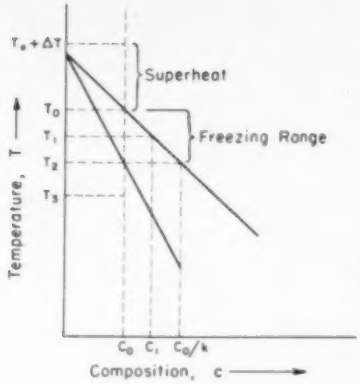


Fig. 3—Portion of equilibrium diagram used to describe freezing of alloy of composition C_o.

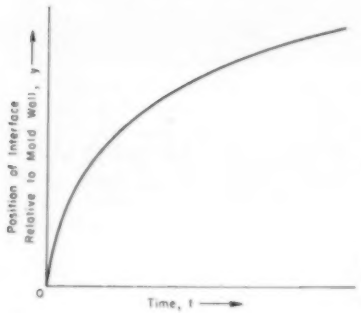


Fig. 4—Position-time plot of solid-liquid interface.

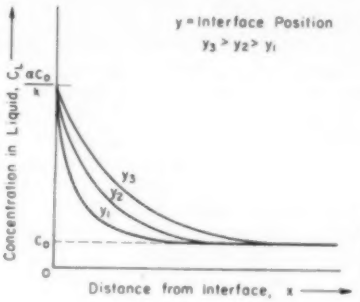


Fig. 5—Solute distribution ahead of interface as a function of interface position.

catalyst has a lattice arrangement and lattice spacing close to that of the nucleating solid, then δT_c should be small[10]. However, the catalyst surface generally has a layer of foreign atoms chemisorbed on it which may either increase or decrease the lattice spacing. Thus, a small amount of solute added to the melt may either increase or decrease the catalytic activity, i.e., change δT_c of the catalyst. The gap in our knowledge centers around the physical forces which lead to the chemisorbed layer, the kinetics of its formation, and the peripheral arrangement it makes with the catalyst surface. At present we must determine the catalytic activity by empiricism.

Ingot solidification

In the conventional method of casting, the alloy having a certain degree of superheat is poured to fill a mold, Fig. 3. The outer rim of liquid metal rapidly cools to the melting temperature, T_o, and begins to undercool. At some degree of undercooling, δT_c, nuclei of solid begin to form at random in this thin, chilled layer of the mold surface. The number of grains formed per unit area of outer surface will depend upon the number of catalysts per unit volume and upon δT_c. If this number is large and δT_c is small, the grains in the chill layer will be small. The size of these grains will also be influenced by the constitutional and thermal parameters of the alloy; however, these effects will be discussed later when we consider the grain size of the equiaxed grains.

Grains in the chill layer are randomly oriented and begin to grow inward because of heat conduction through the mold. As the grains become columnar, several things happen: 1) Because of the slow diffusion rate of solute in the liquid, solute builds up rapidly at the interface[4] to the value of $\alpha C_o/k$, where C_o is the initial concentration of solute in the melt, k is the ratio of the solubility of solute in the solid to the solubility in the liquid at a certain temperature, and α is a constant which depends on the detailed interface morphology. As the solute build-up occurs, the interface temperature decreases along the liquidus line. 2) For most alloys the interface will have a dendritic morphology. Because of this morphology, a preferred orientation will develop in the columnar grains which increases the grain width by a factor of 5 to 10 over that in the chill zone[5]. 3) The temperature gradient in the solid conducts away not only the latent heat of fusion but some of the superheat from the liquid as well; thus, the temperature gradient in the liquid at the interface decreases as the interface advances inward.

Depending upon the thermal parameters of the alloy and mold, the interface advances inward from the mold wall in a manner based on time, as illustrated in Fig. 4. Since the velocity of freezing is decreasing with the distance of the interface from the mold wall, the solute distribution in the liquid ahead of the interface will be as illustrated in Fig. 5, as a function of interface position. This assumes that the interface concentration remains constant, which is not quite true. Since every point in the liquid has a definite concentration of solute, a definite freezing temperature is determined from the equilibrium diagram. We shall speak of this as the equilibrium temperature distribution in the liquid as contrasted to the actual temperature distribution, which is determined by heat flow. The equilibrium temperature distribution and the actual temperature distribution as a function of interface position are illustrated in Fig. 6.

It can be seen that a region of liquid exists in which the actual temperature is below the liquidus temperature. This liquid is said to be constitutionally supercooled and is therefore unstable with respect to the nucleation of new grains. When the critical value of supercooling, δT_c, is reached at some point in the liquid, nucleation will be catalysed and grains will form in the liquid ahead of the interface, thus prohibiting further growth of the columnar grains. This is illustrated in Fig. 7 and constitutes the onset of equiaxed nucleation.

A quantitative treatment of this problem shows that the ratio of equiaxed zone width to columnar zone width varies in the following way:[4] 1) inversely proportional to the effective superheat which is equal to the actual superheat plus the freezing range, 2) inversely proportional to a function of the thermal parameters of the alloy. For example, as thermal conductivity of the solid decreases because of alloying, this function decreases. 3) Inversely proportional to δT_c, 4) proportional to the freezing range of the alloy. This variation of the ratio of equiaxed zone width to columnar zone width agrees with the available facts[5, 6]. The quantitative treatment[4] also shows that, to a first approximation, it is the ratio of temperature gradient in the liquid at the interface to velocity of freezing that determines the onset of equiaxed nucleation, a prediction that is also in agreement with experiment[5].

Grain size

Let us now consider the grain size of equiaxed crystals. First, consider the nucleation and growth of a spherical grain in an infinite bath of liquid which is undercooled. If the grain nucleates at the temperature T_0 in Fig. 3, the departure from equilibrium at the interface causes it to grow very rapidly—about 10^4 cm per sec. After it has grown a few atomic layers, its interface temperature and concentration lie on the liquidus line below T_0 and the particle still grows rapidly, but now at a rate determined by the rate at which heat can be conducted away—about 1 to 10 cm per sec. As it grows, the solute concentration at the interface increases to C_0/k and thereafter the particle grows at the constant interface concentration C_0/k at a rate which depends on the rate of heat conduction—still about 1 to 0.1 cm per sec.

However, if the grain nucleates at temperature T_1, it follows the same initial growth rate path but quickly slows down as the interface concentration approaches C_1. The concentration cannot build-up to C_0/k in this case; it cannot be greater than C_1 since the interface temperature cannot be below the bath temperature. The grain then grows at a rate determined by the diffusion of solute in the liquid—about 10^{-3} to 10^{-4} cm per sec. We may consider that the grain has essentially stopped growing when it reaches this state and this will be its ultimate grain size. Its size depends upon the distance it must grow in order to build up the concentration to C_1 at the interface. A quantitative treatment of this problem shows that the grain size, d, varies in the following way:[10] 1) proportional to δT_c, 2) proportional to the partition coefficient, k, and 3) inversely proportional to the liquidus slope.

The preceding discussion leads to the minimum possible grain size since it assumes that all the latent heat can be conducted away. In an actual ingot, a number of grains will nucleate when the undercooling δT_c is reached ahead of the columnar interface. These grains will rapidly grow to the size d provided the latent heat can be conducted away. In adjoining volumes of liquid undercooling δT_c still exists, so nuclei will form here and grow to the size d. In this way the ultimate grain size in the equiaxed zone will be d. However, if the rate of heat conduction is poor, the first few grains to nucleate will raise the local temperature above T_1 because of their latent heat evolution, and thus no new grains can nucleate. These primary grains may grow to a large size before regions of liquid are again undercooled to δT_c so that new grains may nucleate. This leads to an ingot size effect, i.e., the larger the ingot, the slower the heat transfer in the central regions and the larger the grains. Thus, grain size, d, also varies inversely as the heat transfer capacity.

Conclusions

From the foregoing, we can see that columnar ingots will be produced if the alloy is cast with a large superheat and if the efficient catalysts are eliminated from the melt (δT_c must be greater than the freezing range). On the other hand, fine grained equiaxed ingots will be produced by casting with a low superheat, by adding an effective catalyst to the melt ($\delta T_c < 1°C$) and by adding an appropriate solute element to the melt. In the future we may thus have, neglecting the ingot size limitation, complete control of the ingot structure and grain size if we know how to produce catalysts with the appropriate δT_c.

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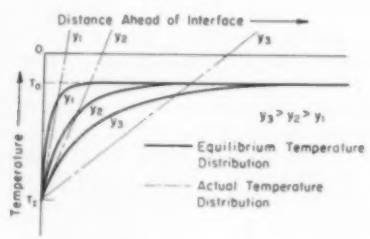


Fig. 6—Degree of constitutional supercooling ahead of interface as a function of interface position.

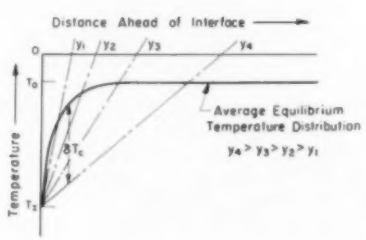
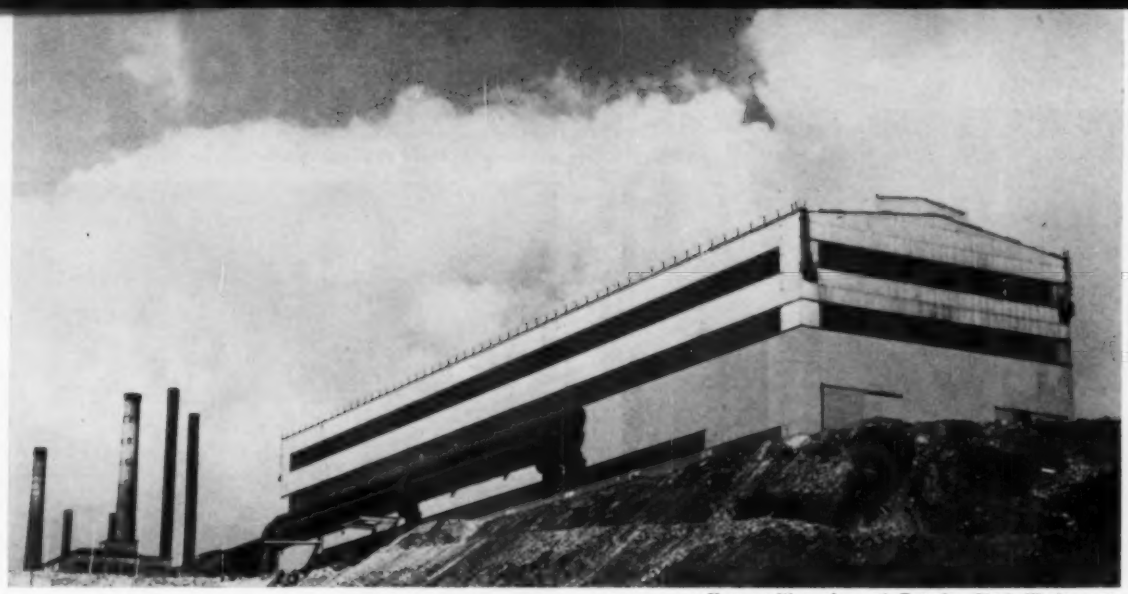


Fig. 7—Approximate description of constitutional supercooling increase in liquid to the critical value needed for equiaxed crystal nucleation.



New melting shop of Brymbo Steel Works near Wrexham in northern Wales.

OXYGEN DESILICONIZING PROVIDES HOT-METAL ELECTRIC STEELMAKING

by H. W. A. Waring and Emrys Davies

A new oxygen desiliconizing process, used to treat hot metal for Britain's newest electric furnace shop, means lower cost production of alloy steels. It is described in a report direct from the Brymbo Steel Works.

BRYMBO Steel Works has developed a unique process which enables hot blast-furnace metal to be pre-refined and charged directly into electric furnaces. This is the main feature of a $6 million development project which makes Brymbo Steel Works in northern Wales one of the two largest all-electric steelworks in Britain.

Unlike other steelworks which have recently installed large electric furnaces, Brymbo wished to continue the operation of its blast furnace, but the electric furnace is not well adapted to the refining of molten iron. Unlike the open hearth, in which an oxidizing atmosphere can be maintained, the electric arc furnace treats metal in a more-or-less sealed-off chamber. Refining action is very slow, and the quantity of basic slag necessary to remove the phosphorus causes severe wear on the electrodes. The result is that the removal of silicon, phosphorus, and more than about 1 pct of the carbon from molten metal is, for all practical purposes, impossible.

H. W. A. WARING is managing director and EMRYS DAVIES works director of the Brymbo Steel Works Ltd., a subsidiary of Guest, Keen & Nettlefolds Ltd.

A common European practice, which enables electric furnace steelmakers to get around this difficulty, is to use the arc furnace in a duplex operation. Blast-furnace metal is first blown in a basic bessemer converter to remove all of the metalloid impurities, and then the blown metal is transferred to the arc furnace for deoxidizing and finishing. But this technique is open to three major objections: 1) the hot metal must contain from 1.5 to 2 pct P to reach a reasonably high finishing temperature; 2) it results in a difficult-to-handle low-carbon metal, since dephosphorization follows decarburization; and 3) the metallic recovery is low, because the finishing slag is high in iron oxide.

Brymbo blast-furnace metal normally contains only about 0.6 to 0.7 pct P—too much for the electric arc furnace to cope with, but insufficient to enable the basic converter to blow the metal at a workable temperature.

Left, charging pre-refining furnace with pit scrap. Below, tapping pre-refiner. Opposite, p. 517, tapping 45-ton electric arc furnace; lance of pre-refiner is seen at right.

In place of the duplex process, engineers at Brymbo have developed a process for pre-refining with oxygen. It meets all the objections of the duplex process, and in addition, it produces a metal with sufficient carbon to make final decarburization in the arc furnace (using the oxygen lance) simple and rapid.

Pre-refining furnace design

The pre-refining unit now in operation at Brymbo Steel Works consists of a deep, circular hearth 16 ft in diam., resting on rockers and rollers so that it can be tilted. The axis of tilt is so arranged that the water-cooled duct for removing fume and products of combustion remains in full operation at all angles. The deep hearth has a dolomite lining, while a high-alumina brick is used on the roof.

As of the 29th of June, this furnace completed 620 heats on the same hearth lining, and some 13,000 long tons of blast-furnace metal were pre-refined. Fettling consumption has been 15 lb of dolomite per long tons of blast-furnace metal were pre-refined. condition. A great feature about this furnace is its flexibility and ease of fettling. The average side-wall life is 250 heats, and the roof life is approx. 200 heats. In the case of both the side walls and the roof it is possible to carry out minor repairs during furnace operating time without serious interference to production, and the roof can be changed in about 1 hr.

For fume removal, a wide water-cooled duct is provided; it connects with a flue leading to a powerful fan and chimney. A fume filtering plant will be installed at a later date to prevent atmospheric pollution.

To control the foaming slag, the hearth is of deep design, and oil burners are mounted tangentially in the walls. These burners incorporate an unusual feature in that their air supply is passed under the furnace hearth to obtain a degree of preheat and cool the hearth at the same time. In addition, this air supply can be enriched with oxygen tapped off the main supply.

Oxygen for pre-refining is injected into the metal through water-cooled lances. One of these can operate while the furnace is tilted; the other must be withdrawn. However, this practice is soon to be replaced by inserting a vertical lance through the roof; this lance can also be used for injecting lime. Such lances can inject oxygen at a rate up to 800 cu ft per min. Oxygen may also be introduced into the metal through *dry* lances, pushed over the working door sill.

Pre-refining practice

At present, the pre-refining operation requires from 1 to 1½ hr. Data on the working of a typical heat is shown in Table I.

Steels now made by this process include: low-carbon, high-silicon transformer steels; high-carbon, high-silicon, silico-manganese spring steels; and special carbon and low-alloy steels for the forging trade. In fact, a wide range of steels can be produced satisfactorily by this method.

Trials on high-phosphorous iron have been carried out recently. Iron containing 1.5 pct P has been successfully pre-refined to 0.08 pct P, while carbon was retained at 1.25 pct. A 1-pct-P iron was satisfactorily pre-refined to 0.02 pct P at 1 pct C.

The average yield of hot metal from the furnace has been 92 pct, which is considered very good. This is carefully checked on every heat. The iron loss via the slag is relatively low, and the average Fe content of the tapping slag is approx. 7 pct.

It is expected that over-all Fe recovery at the plant will be increased still further in the next few months by recharging to the pre-refiner some of the slag from the final decarburization in the arc furnaces. This arc-furnace slag tends to be high in iron oxide and low in phosphorus.

A feature of the Brymbo pre-refining practice, again probably unique to Great Britain, is the employment of fluidized powdered lime and limestone fed into the metal together with the stream of oxygen. Tests indicate that this is a far more effective way of making a fluid and reactive basic slag than that of relying on the use of solid material thrown onto the metal bath.

An additional advantage of the pre-refiner, which may not be evident at first, is its ability to absorb quantities of large-sized and awkwardly-shaped scrap. Large lumps of pit scrap cannot be melted

satisfactorily in the arc furnace because they tend to cause electrode breakage; in the pre-refiner, however, up to 25 pct pit scrap has been melted successfully. High silicon skull and scrap can similarly be melted.

Hot metal from the pre-refiner is transferred to one of the three new 45-ton electric arc furnaces where the scrap has been brought to a state of incipient fusion.

Arc furnace operation

The 45-ton arc furnaces in the new melting shop at Brymbo operate on a charge of 45 to 50 pct hot metal. They are able to turn out heats on a 4½ hr tap-to-tap basis.

A typical electric furnace heat made under these conditions is as follows:

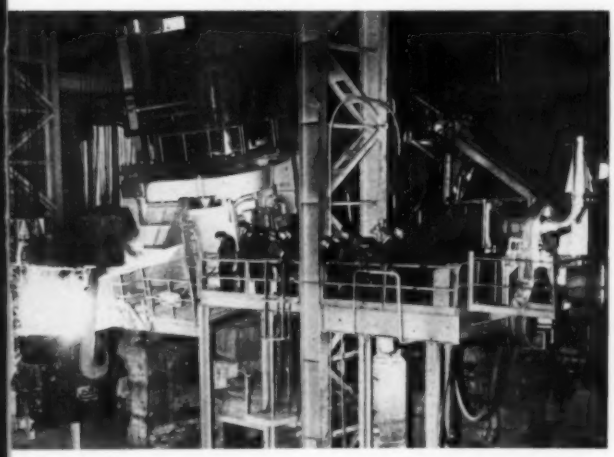
2:50 pm—Last tap; furnace fettled.
3:35 pm—25 long tons of scrap charged; power on at 325 v and 20,000 amps to melt down.
5:05 pm—20 long tons pre-refined iron charged.
5:35 pm—Temperature 1520°C.
5:50 pm—Oxygen blown intermittently for 25 min through ¾-in. pipe; suitable additions of lime and limestone made to slag.
6:35 pm—Sample taken, 0.56 pct C.
6:55 pm—Managanese added.
7:20 pm—Tapped silico-manganese steel containing 0.55 pct C, 0.82 pct Mn, 1.9 pct Si, 0.034 pct S, and 0.025 pct P.

For steel made in this way, the electric power consumption works out at an average of 395 kw-hr per long ton, and the oxygen consumption in the electric furnace at 460 cu ft per long ton.

Features of the new melting shop

The new oxygen-electric melting shop consists of two parallel bays 432 ft long by 50 ft wide. In the charging bay itself there are three 5-ton Birlec arc furnaces, one 150-ton mixer, and one 20-ton oxygen pre-refining vessel.

Immediately behind the furnaces are the storage bunkers which contain fluxing materials fed into the furnaces by a mobile charger. The working platform for the furnaces is 18 ft high and is so designed that valuable floor space is available under it for the storage of raw materials. Railway lines are laid under the platform to enable the slag cars to be charged without interfering with the operations on the working platform.



Electric arc furnaces

The three electric furnaces are top-charged, direct-arc tilting furnaces with a shell diam of 16 ft. Each furnace has three 16-in. diam. vertical graphite electrodes which are clamped by high-conductivity, water-cooled copper castings. Pressure on the clamp is provided by a heavy spring, which is released for electrode adjustment by an air cylinder. The slagging door and side door are also operated by air. The arches and jambs of the doors, the furnace shell, and the roof rings are water-cooled, and each furnace is extensively hooded for fume removal.

Each electrode is controlled by a motor and winch. A special type dc generator is provided for each electrode winch motor. The field excitation of the generator is controlled from opposed voltage and current components of the furnace power circuit; this instantly produces a corresponding, but greatly magnified, variation in the generator voltage applied to the winch motors. Thus, the winch motors are energized in proportion to the degree of out-of-balance in the furnace power circuit. The electrodes move rapidly to compensate for large changes and proportionately slower for small variations. The electrode motor winches can also be controlled by hand, but the automatic control enables the furnace operator to have complete control over the heat input to the furnace. By merely pressing a button the operator is able to increase or decrease the heat input; it will then remain constant until it is necessary to make further adjustment.

The transformer on each furnace is designed to give a maximum output of 12,500 kva from a 33 kv, three-phase, 50 cycle supply. The secondary voltage can be varied from 325 to 120 v in 20 steps.

Oxygen plant

Because of the large amount of oxygen used in this process, it was necessary to build an oxygen plant at Brymbo. It was decided to install a 24,000 cu ft per hr plant made by Air Products (Great Britain) Ltd.

Conclusions

A new and potentially important steelmaking process is the focal point of a $6 million development project now completed at Brymbo Steel Works Ltd. in northern Wales.

It is expected that Brymbo's pre-refining process will spread to other steelworks, since it can be utilized not only for the electric process but also for other types of steelmaking.

Table I. Operating Characteristics of Pre-refining Furnace

Analysis of blast-furnace hot metal, pct	
4.15 C	0.63 P
0.47 Si	0.85 Mn
0.048 S	
Temperature of blast-furnace hot metal, °C	1385
Analysis of prerefined metal, pct	
0.04 S	
1.68 C	0.036 P
Si Trace	0.14 Mn
Analysis of final slag, pct	
43.2 CaO	9.1 P_2O_5
14.8 SiO_2	0.9 Fe
Total heat time, charge to tap, hr	1 to 1½
Oxygen per long ton blast-furnace metal, cu ft	1030
Scrap melted, pct	6.55
Overall efficiency of oxygen usage, pct	100 plus
Overall yield of metal, pct	93
Rise in temperature, °C	150

SOVIET EXHIBITION

Features

WITH the news that Frol R. Kozlov, First Deputy Chairman of the USSR Council of Ministers, was to open the Soviet Exhibition in New York's Coliseum on June 30th, we hied ourselves to that massive exposition palace . . . for Mr. Kozlov is a metallurgist, and we travel miles to see metallurgists!

T'was a lovely day for such an expedition . . . as we dashed through the subways—air-cooled at 96° —we thought of glaciers, ice factories, and the air-conditioned Coliseum. Whatever else the exhibit had to offer, at least a few hours of comfort were assured.

We found things in a state of confusion. . . President Eisenhower was expected momentarily and Mr. Kozlov was nowhere to be found. We determined to return another day.

Two days later. . . starting with an hour long telephone barrage we thought that we had things set up. "Go to the 60th street entrance" we were told. . . and to that entrance we went. "Go to the Coliseum office building on 58th street" we were told at the 60th street entrance. Arriving exhausted at the press office in the bowels of the Coliseum, we learned, "The gentleman from the Academy of Science whom you wish to see is on the phone to Moscow." "A-ha," we thought, "getting the straight word before talking to the JOURNAL OF METALS". Noses held high, we wandered off into the maze of exhibits to find our man, Mr. Ademski. "Metallurgist? I am a petroleum engineer," was his response to our first query. "Ah yes," said an interpreter, "you should see Mr. Nikanov, who is with the Institute of Metallurgy of the Academy of Science".

We located Mr. Nikanov, who was adjusting a machine for the continuous casting of micron diameter wire. Deciding we had better look about until all was working well, we spied a beautifully constructed model of a new Soviet blast furnace and open-hearth furnace plant, and a little further on a model of a continuous casting line for slabs. At the fashion show, there were several more beautifully constructed models.

The first piece of testing equipment that we noticed was Kornilov's centrifuge for creep, rupture, and bend tests which was described in the March 1958 issue of JOURNAL OF METALS. We learned that the model on display was an early one and that today's are much more automatic.

We ran onto a spectrograph, labeled the DFS-12 fast spectrograph for reading in the range of 2000 to 6500 Å. We also located an electron microscope labeled the UMEB 100 which reminded us a good deal of the IRSID model.

We found a model of a vacuum degassing apparatus designed by Samarin. Twenty-five ton ladles are placed in the vacuum chamber. Pressures as low as 1 mm Hg are used for degassing on a 12 to 15 min operation.

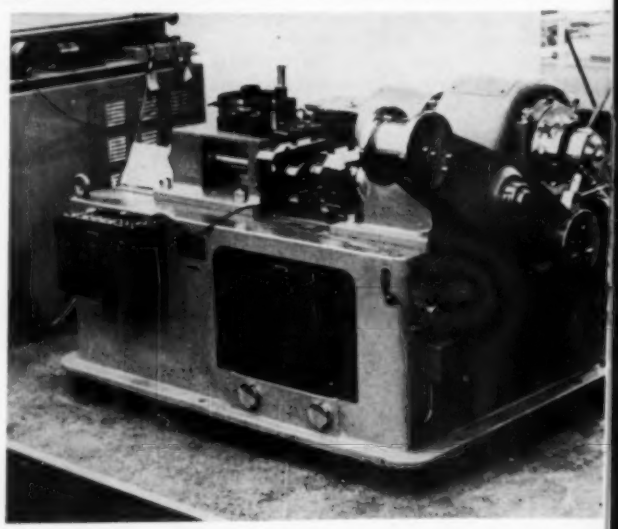
Other testing equipment shown included a general purpose resonance testing machine for bending or torsion fatigue tests. Adjusting the programing device, the operator got the machine off to a flying start—very impressive. We also inspected a plastic deformation machine which appeared like many we had seen previously.

Oh yes. . . Mr. Nikanov. . . we found him breathing a sigh of relief as his micron wire machine began producing. "Mr. Nikanov, would you explain to us something about this machine," we said. A smile. . .an outpouring of Russian. . .and a blank look on our part, as our Russian is weak. Nikanov had an idea: "Können sie Deutsch sprechen?" . . ."Ja, Ja," we replied and we were soon roaring on toward an explanation of the equipment. We learned that the machine is designed to produce micron diameter wire continuously from fused metals, such as copper, cast iron, tin, germanium, silver, and gold. Diameters from 2 to 100 μ are possible. The wire is used for windings in small transformers and various electrical relays.

Mr. Nikanov first explained, then demonstrated the equipment that we have already mentioned and which is illustrated on these pages.

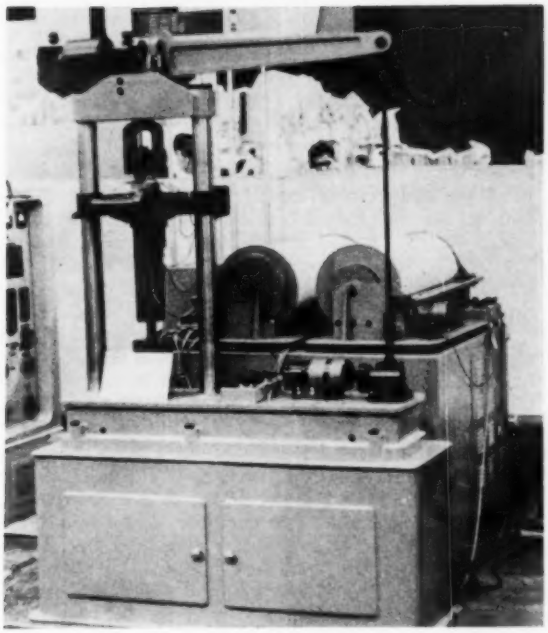
He paused at the last piece of equipment, wiping dust from the exhibit, "Viel Staub in New York." (Much dust in New York.) We couldn't disagree, "But there are many nice residential areas around New York," we explained. "I don't think that I care for New York very much. We came all this way to show you what we have, and now you must come to Moscow." With that we said "Aufwiedersehen" and went home to see if there was enough loose change in petty cash to finance the trip. F.W.S.

Below, general purpose resonance testing machine for bending or torsion fatigue tests, with programming: frequency 25 cps, max bending moment 300 kg-m, max amplitude of travel 28 mm, max amplitude angular oscillation + or— 5°, and max torque 1000 kg-m.

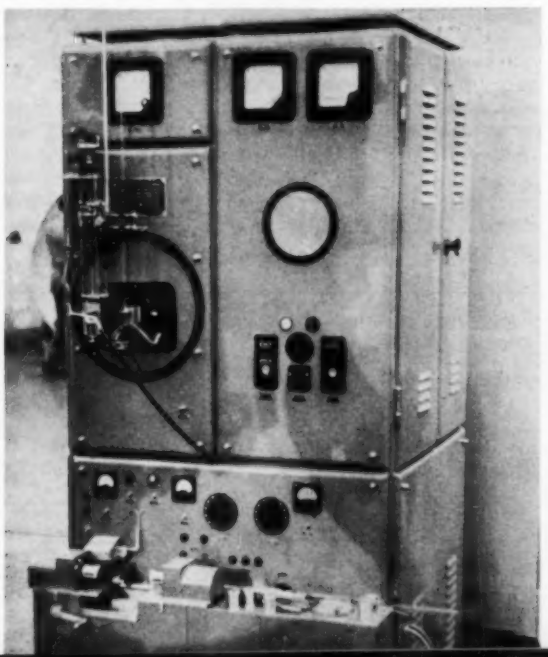


IN NEW YORK

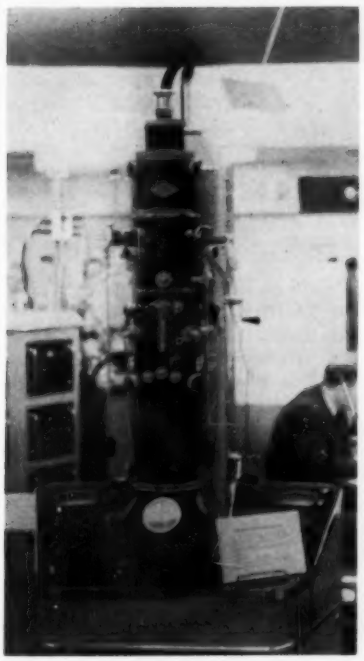
Metallurgy



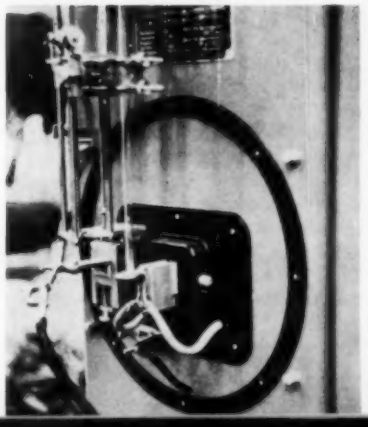
Above, plastic deformation machine: max tensile force 6000 kg, max torque 5800 kg-cm, axial strain up to 8 pct, torsion strain up to 8 pct, tabular sample working section length 120 mm, inside diam 24 mm, test duration 40 sec.
Below, continuous casting machine for micron diam wire.



"Really, Mr. Nikanov!"



Right, electron microscope UMEB 100, 100 kv acceleration voltage, X250 to X150,000 admissible resolution 15Å.



Right, close up of continuous casting machine shown at left.

OXYGEN OPEN-HEARTH PRACTICE IN THE USSR

This discussion on the use of oxygen in Soviet open-hearth practice was presented at the 1958 Journees Internationales de Siderurgie in Liege, Belgium. Written by Engineer Myssovski, it was presented in English by Engineer Morozov. JOURNAL OF METALS *wishes to thank Dr. Pierre Coheur of CNRM for making it available for publication.*

Oxygen in open-hearth steelmaking is finding an increasingly wide use in the USSR. At present, open-hearth furnaces in a number of steel works are operating with oxygen. More than 10 million metric tons of rimming and killed steel were produced with the use of oxygen in 1957.

The total capacity of the oxygen plants for open-hearth departments is about 90,000 cu m per hr. Oxygen plants are being equipped with air separation units with capacities of 3600, 5000, and 10,000 cu m per hr.

Oxygen enrichment

At all steel works, oxygen is fed directly into the flame. On furnaces operating on fuel oil, oxygen is fed into the oil burner under the jet of fuel. On furnaces fired with a mixture of coke-oven and blast-furnace gases, special water-cooled lances for oxygen injection are installed in the furnace ends at the sides of the gas ports in the brick lining. The degree of oxygen purity is about 95 pct, and the pressure of oxygen fed into the flame varies from 6 to 9 atm at the furnace.

As a result of extensive investigations concerning the thermal efficiency of the furnace with oxygen injection, it has been found that, when the air in the furnace is enriched with oxygen in amounts up to 25 to 30 pct, the flame temperature rises by 100° to 150°C; the fuel combustion rate increases; and the flame volume diminishes. Heat losses from waste gases also decrease, and because of the reduced volume of combustion products, the fuel rate can be increased with the same draft facilities. All this leads to an improved heat utilization in the furnace working chamber (Table I) and an increased absorption of heat by the charge.

When oxygen is injected into the flame during the meltdown period, the heat transfer to the bath proceeds much more intensively than without oxygen. However, due to greater radiation of the oxygen-enriched flame, the roof of a furance—especially after the formation of the molten bath—is heated to higher temperatures than with a normal flame. If the roof consists of silica brick, the oxygen injection must be confined to the period preceding the formation of the slag cover, and this reduces the efficiency of oxygen use. Therefore, all open-hearth furnaces in the USSR operating with oxygen are equipped with roofs made of non-spalling magnesite-chromite brick. With such roofs, it proved possible and desirable to continue oxygen injection after the formation of the slag cover. This is one of the reasons for the higher output of furnaces with magnesite-chromite roofs.

As a result of increased oxidizing capacity of the furnace atmosphere when injecting oxygen into the working chamber, the oxidizing processes are intensified. Decarburization is of the greatest importance, since as a result of its intensification, considerable change in the thermal efficiency of the furnace takes place. Increased heat from the burning of carbon monoxide enables the fuel rate to be reduced, which results in fuel saving. The heat absorbed by the bath is also improved, because the heat of the burning carbon monoxide is released in close proximity to the surface of the bath.

Reduction in the fuel rate is not only possible, but necessary, since otherwise the temperature of the brickwork rises to dangerous levels. In addition, an incomplete combustion of fuel in the working chamber occurs unless the fuel rate is reduced.

With the increased weight of the charge, the volume of carbon monoxide released per unit of hearth area also increases. Therefore, the larger the charge, the more important the changes in thermal efficiency of the furnace brought about by the after-burning of carbon monoxide. For example, heat obtained from the after-burning of carbon monoxide in the 200-ton open-hearth furnaces of the Zaporozhstal steel works, using 30 pct oxygen-enriched air, increased up to 60 to 70 pct of the heat input. The total heat input in the working chamber remained constant. In a number of cases, with enrichment of air up to 30 pct O_2, the fuel supply to the furnace during the oxidation periods was cut off altogether for rather long periods of time.

With the scrap-ore process, the degree of fuel utilization increases from 20 to 30 pct, without oxygen; up to 70 pct when oxygen concentration in the air is about 25 pct; and up to 93 pct when oxygen concentration in the air is raised up to 30 pct. Thus, heat losses with oxygen enrichment up to 30 pct are almost entirely offset by the heat of the chemical reactions in the bath and the heat of the carbon monoxide after-burning, as well as by the heat recovery from the combustion products.

Table I. Change in Fuel Efficiency with Oxygen-Enriched Flame (Without Consideration of Complete Burning of Carbon Monoxide)

	Oxygen Content of Air, Pct		
	21	25	30
Oxygen consumption, cu m per hr	—	1300-1800	2500-3000
Fuel efficiency factor:			
during charging and warming up	0.43	0.47	0.50
during melt-down	0.26	0.31	0.38

Table II. Performance Data for Heats with Enrichment of Air up to 30 pct O_2

	Oxygen Enrichment, Pct		
	Up to 25	Up to 30	
		A	B
Time, hr-min			
fettling	0-28	0-19	0-9
charging	1-07	0-52	0-28
warming up	0-47	0-36	0-27
hot metal pouring	0-19	0-11	0-08
refining	2-32	1-57	1-18
finishing	1-52	1-21	1-07
overall heat time	7-05	5-16	3-38
Furnace output, metric tons per hr	28.0	37.2	56.3
Equivalent fuel consumption rate, kg per metric ton	109.2	80.5	93.0
Oxygen consumption, cu m per metric ton	40.7	61.0	53.0

Performance data

Oxygen is generally injected from the beginning of charging until the end of the melt-down. The degree of air enrichment is about 25 pct.

The output of an oil-fired open-hearth furnace, operating by the scrap-ore process on cold pig-iron, is increased by 13 to 15 pct, and fuel consumption is reduced by 5 to 7 pct when the oxygen consumption rate is 18 to 22 cu m per metric ton of steel.

The increase in the output of the 200-ton open-hearth furnaces at the Zaporozhstal steel works, fired with mixed gas and operating with 65 to 70 pct hot metal in the charge, is 17 to 20 pct. The reduction in fuel consumption rate is 15 pct; with the oxygen consumption rate about 35 cu m per metric ton. The average heat time is about 7.6 hr, and the annual output of a furnace is about 210,000 metric tons.

The output of the 370-ton tilting open-hearth furnaces at the Azovstal steel works, fired with mixed gas and operating with 73 to 75 pct of phosphorous pig iron in the charge, has been increased by 19 pct and the fuel consumption reduced by 6 pct, when the oxygen consumption rate is about 35 cu m per metric ton.

On the 370-ton stationary open-hearth furnaces of the Nizhny-Tagil steel works, operating with 70 pct hot metal in the charge and fired with a mixture of coke-oven and blast-furnace gases, the output has been increased by 20 pct and the fuel consumption reduced by 18 pct, when the oxygen consumption rate is 25 to 30 cu m per metric ton.

The effect reached thus far is not the maximum that may be expected. The effectiveness of oxygen use will increase as the capacities of the auxiliary facilities are enlarged to correspond to the possibilities of the furnaces.

When enriching air up to 30 pct O_2, the output of the furnaces is increased by 50 to 70 pct, and the equivalent fuel consumption is reduced by 30 to 40 pct compared to the non-oxygen furnaces. Table II shows the performance data for experimental heats with air enrichment up to 30 pct O_2 in the 200-ton furnaces of the Zaporozhstal steel works. The data given in the table shows the high efficiency of a further increase of air enrichment with the scrap-ore process.

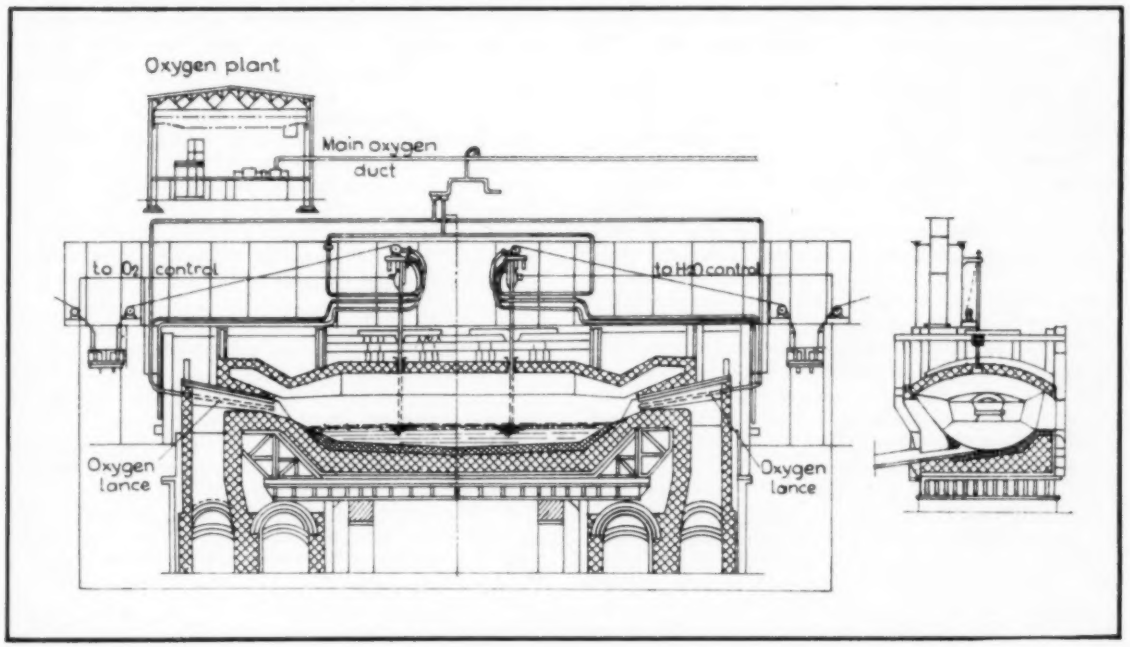
Direct oxidation in the bath

In 1951, tests were started at the Zaporozhstal steel works of equipment for oxygen injection into the bath by means of water-cooled lances, introduced vertically through an opening in the main furnace roof. As a result of these tests, standard equipment for 200 and 500 ton furnaces was developed (Fig. 1).

During oxygen injection, water-cooled lances are immersed to the level of the slag metal interface. At present, extruded copper nozzles are used for oxygen injection; the main oxygen jet is split into five smaller ones. The average life of water-cooled lances is 110 heats.

This method of oxygen injection is the most convenient in stationary open-hearth furnaces and is now widely used in the USSR. At present, open-hearth and electric furnaces at a number of steel works are provided with roof injection units.

Fig. 1—Soviet roof unit for injecting oxygen into the open hearth bath.



At the Azovstal steel works, the roof oxygen injection units have not been adopted because of the difficulties involved in installing these units on tilting furnaces. But oxygen is injected through openings in the furnace back wall.

The losses of iron into the slag in the form of ferrous oxide are important, since they reduce considerably the yield of molten steel and result in increased consumption of deoxidizers. This increased ferrous oxide content of the slag arises, unless the lances are immersed in the bath. With proper immersion of the lances and a good piercing ability of the oxygen jets (as at the Zaporozhstal steel works) there is no rise in ferrous oxide concentration in the slag, and the yield of metals is not reduced.

The consumption of injected oxygen for decarbonization of a bath with high initial carbon content can be lower than the theoretical consumption, due to the fact that oxygen coming from the furnace atmosphere takes part in the bath oxidation reaction. But, with reduction of oxygen content in the metal, the oxygen efficiency is reduced, since the amount of oxygen coming from the furnace atmosphere decreases with the weakening of boiling and bath agitation. Moreover, a considerable quantity of oxygen is consumed for iron oxidation. Thus, at a low carbon content, the actual oxygen consumption rate may exceed the theoretical rate by five to seven times.

At Zaporozhstal: Oxygen injection into the bath when making steel with carbon contents lower than 0.12 pct is practiced at the Zaporozhstal steel works. Prior to the melt-down, oxygen is injected into the flame; thermal conditions and steelmaking practice maintained during the heat are the same as for heats without oxygen. The injection of oxygen into the bath is started at a carbon content of 0.4 to 0.5 pct and finished before deoxidation at a carbon content of 0.08 to 0.10 pct.

As a rule, during oxygen injection, fuel supply to the furnace is reduced because of a heavy release and afterburning of carbon monoxide over the bath and a considerable rise in bath temperature, which results both in shortening heat time and saving fuel.

The average decarbonization rate during boiling increases from 0.35 to 0.45 pct C per hr to 0.6 to 0.7 pct per hr. The maximum carbon oxidation rate during oxygen injection is 1.8 to 2.0 pct per hr. The rise in metal temperature per point of carbon removed, which usually is 1.2° to 1.3°C, increases to 1.7° to 1.9°C during oxygen injection into the bath.

Because of the oxygen injection, the heat time is reduced by 25 to 40 min. The oxgen consumption rate for injection into the bath varies from 5 to 6 cu m per metric ton. Increase in furnace output is 4 to 6 pct with the same saving of fuel, and the quality of the metal is not impaired.

In view of a considerable reduction in furnace life when oxygen is injected into a bath with a high initial carbon content, oxygen injection is not used when refining pig-iron grades.

At Azovstal: Oxygen injection into the bath during the refining period is used only in the conversion of phosphorous pig irons at the Azovstal steel works. The amount of flue dust in the waste gas is one and a half to two times less than in the conversion of ordinary pig irons, due to the relatively low bath temperature particularly during the refining period, and the presence of a thicker slag layer. No reduction of furnace life has been observed.

Furnace output due to oxygen injection is increased by 5 to 9 pct, and fuel consumption is reduced by 7 to 10 pct. Oxygen consumption rate for bath injection is 5 to 7 cu m per metric ton, and, again, the quality of the metal is not impaired.

Refractory life

Suspended magnesite-chromite brick roofs are employed on all furnaces in which oxygen is used. This type of brick is also coming into use for slag chamber roofs. In the upper layers of checkers in gas and air regenerators, fosterite brick is used.

When using oxygen for injection into the flame, the life of open-hearth furnaces is not reduced. For example, average roof life of the 200-ton open-hearth furnaces at the Zaporozhstal steel works in 1957, when using oxygen for both air enrichment and injection into the bath, was 466 heats, as compared to 498 heats when using oxygen only for air enrichment. The rate of roof wear when injecting into the bath is higher than without injection, especially along the roof center line.

When oxygen is used for injection into the flame, the dust deposits in the checkers are comparatively small, while with the injection of oxygen into the bath, heavy dust deposits in the checkers are observed, due to intense dust formation in the working chamber. When injecting oxygen into the bath, the life of the checkers is reduced.

Conclusions

As a result of research work and full-scale trials, the following methods of oxygen use are being widely employed in open-hearth steelmaking at present:

1) Oxygen injection into the flame via a burner or special water-cooled lance is used for increasing the thermal efficiency of the furnace from the beginning of charging until the end of the melt-down.

Air enrichment does not exceed 25 pct. At the oxygen consumption rate of 25 to 35 cu m per metric ton, this method of intensification of the melting process ensures a 17 to 20 pct increase in the output of open-hearth furnaces and a 10 to 15 pct saving of fuel.

2) Direct oxidation of the bath with oxygen is used in making low-carbon steel grades (less than 0.12 pct C). Oxygen injection into the bath by means of a special roof injection unit is the best method. The use of oxygen injection in making low-carbon steels results in an increase of open-hearth furnace output by 4 to 6 pct and a similar reduction in fuel consumption. The oxygen consumption rate is 5 to 6 cu m per metric ton.

3) At the Azovstal steel works, oxygen is injected into the bath during the refining period when converting phosphorous pig iron in tilting furnaces. Oxygen is introduced by means of lances inserted through openings in the back wall of the furnace. The increase in output is 5 to 9 pct with a fuel saving of 7 to 10 pct and an oxygen consumption rate of 5 to 7 cu m per metric ton.

4) The cost of metal made with oxygen is not greater than with normal steelmaking techniques, and the quality of the metal remains the same as before.

5) It is desirable to combine the use of oxygen with all-basic furnace construction.

RADIATION DAMAGE IN FERROUS METALS

Through the selection of illustrative data, the author presents a picture of iron and steels under irradiation. The greater portion of the work done has been of an engineering nature, and the conditions of irradiation, temperature, and exposure time do not cover ranges as large as might be desired.

by D. E. Thomas

IN a nuclear reactor, conditions of neutron flux and temperature which a material must withstand vary widely, depending upon location. Obviously, the highest neutron flux occurs in the core of the reactor. The neutron flux decreases rapidly with radial distance from the core through the internal shielding, the reactor container or pressure vessel, and the biological shielding. Operating temperatures also vary roughly in the same way. Both neutron flux and temperature depend upon whether the reactor is water-moderated and water-cooled, liquid metal-cooled, homogeneous, and so on.

The Pressurized Water Reactor (PWR) at Shippingport, Pa., serves to indicate some practical parameters. In the case of the core, the maximum fast neutron flux is about 4.2×10^{14} nv. Assuming that one might desire to have core components in service for 20 years, the integrated fast flux would amount to 2.6×10^{22} nvt. The temperatures in this region are in the range 540° to 750°F. In the thermal shields, the flux is about 3.6×10^{13} nv, and the temperature 550° to 575°F. In 20 years the integrated exposure would be 2.3×10^{21} nvt. In the pressure-vessel wall, the flux and temperature are 3.6×10^{11} nv and 500° to 600°F respectively, the integrated flux over 20 years being 2×10^{19} nvt.

Steels have been utilized in all of the above-mentioned locations in one reactor or another. The suitability of steels within the primary system of a reactor depends upon resistance to corrosion by the coolant, and the amount of radioactivity placed in the primary coolant by the steel, as well as radiation-damage properties. We shall here confine ourselves to the irradiation-damage aspect of the problem.

Radiation-damage mechanisms

The passage of energetic neutrons or other particles through a metal lattice produces a number of kinds of alterations or defects. There is, at the same time, a marked tendency for these defect configurations to anneal out, or to seek more stable configurations. The combined effect determines property changes, although there may be additional effects, usually small, brought on by the introduction of foreign atoms by transmutation. The various forms of lattice disruption caused by collision of energetic particles are well described in the literature[1] and will only be summarized briefly here. The simplest forms of lattice damage are *the vacancy* and *the interstitial*, which occur as follows: an incident particle possessing sufficient energy on colliding with the nucleus of a lattice atom can knock the atom from its lattice site, thus creating a vacancy. The knocked atom may subsequently collide with another lattice atom causing another vacancy, and so on, until the energy originally transferred is expended. Some of the atoms involved are left in interstitial positions. Some of the secondary knock-ons may displace an atom from the lattice and remain in its place. This has been termed a *replacement collision*.

Another form of lattice damage is the *thermal spike*. There is a considerable amount of vibrational energy imparted to the lattice along the tracks of charged particles or energetic knock-on atoms. This energy is transmitted to adjacent lattice atoms and dissipated into the surrounding lattice. Thus, a more or less cylindrical region around the track is heated momentarily to relatively high temperatures. It has been estimated that temperatures above the melting point may be reached for 10^{-12} to 10^{-11} sec in a region containing about 1000 atoms. Accompanying strain in the surrounding lattice may produce dislocations.

Another process involving large numbers of atoms is the *displacement spike*. As an energetic displaced atom slows down, the distance between displacement collisions decreases until, near the end of its track, the distance becomes approximately one interatomic spacing. This results in a shower of displacements, involving perhaps 10^4 atoms, and may be viewed as a region in which melting and rearrangement occurs, followed by rapid cooling. This may also be viewed as the formation and collapse of a large multiple vacancy. Dislocations may be generated around the spiked region.

There is not complete agreement about the details of these forms of lattice damage, particularly in the case of thermal and displacement spikes.

As soon as the lattice defects are formed, they tend to anneal out by complex processes which vary with temperature.[2] Vacancies and interstitials tend to recombine, thus annihilating each other. They may also migrate to grain boundaries. These processes do not appear to account adequately for observed changes in strength, and other mechanisms have been proposed. Interstitials may agglomerate to form an interstitial plane of atoms similar to a stacking fault, or the extra atom may be accommodated along a lattice line of dense packing. The latter configuration, called a *crowdion*, is constrained to move in a

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fixed crystallographic direction, and its motion may be impeded by impurity atoms. It is believed that these configurations affect the ability of the material to flow; both directly and by their participation in Cottrell-anchoring of dislocations.

Interstitials and vacancies may affect metallurgical processes through their effect upon diffusion. The increased number of vacancies resulting from irradiation should accelerate diffusion and diffusion-controlled processes. Such an effect is, however, generally observable only over small distances for two reasons: at high temperatures, the normal thermally-produced vacancy concentration is large compared to the irradiation-induced vacancy concentration; and at low temperatures, mobility is small. The formation of vacancies and interstitials and the action of replacement collisions introduces disorder to ordered lattices.

Spikes, in addition to the effects of the vacancies and interstitials accompanying their formation, have the effect of leveling concentration gradients, quenching-in new phases, promoting disorder, and perhaps annihilating nuclei of a new phase. These processes have been summarized in the literature.[3,4]

Irradiation promotes precipitation in the age-hardening systems copper-beryllium and nickel-beryllium, while in the copper-iron system, there is evidence for both precipitation and resolution. Similarly, irradiation promotes transformation in tin and phosphorus; has no effect in uranium-chromium alloys, and promotes the formation of the gamma phase in the uranium-molybdenum and uranium-columbium systems at temperatures where that phase is unstable.

The effect of irradiation on metallurgical processes varies among particular cases, as would be expected, because the rate of defect production . . . the rate of disappearance or formation of defect configurations . . . the rate of the normal metallurgical process under consideration . . . and the microstructure combine to give an overall effect. The importance of neutron flux, irradiation time, and irradiation temperature is thus obvious.

There have been attempts to rationalize irradiation effects by drawing analogies. Correspondence between irradiation effects and cold work, increased temperature, and alloying has been suggested, but these all fail. The evidence is that irradiation places the material in a state which cannot be duplicated by any other means.

Radiation damage . . . in iron

Before proceeding to the consideration of irradiation effects in steel, it is of interest to examine the behavior of pure iron under irradiation. The tensile properties of iron after irradiation at 176°F are shown in Fig. 1 as a function of integrated fast-neutron flux[5]. Yield and tensile strengths increase with increasing exposure. The yield strength appears to be approaching saturation at 10^{20} nvt. Reduction in area remains unaffected. Total elongation decreases from an initial value of 60 pct to a value of 34 pct at 10^{20} nvt (fast) and gives indication of approaching saturation. The change in total elongation is largely the result of a decrease in uniform elongation. A drop-in-load type of yield point was introduced by irradiation. Similar results were obtained by Kunz and Holden[6] on single crystals of iron irradiated to 10^{19} nvt (thermal) at a temperature <122°F. Fig. 2 shows a rise in yield strength with indications of a yield point due to irradiation, and only slight changes in ultimate strength. The strain-hardening index is lowered by irradiation.

Table I. Effect of Irradiation Temperature on Yield Strength[6] of Iron
Exposure, 10^{17} nvt (fast)

Irradiation Temperature, °F	Yield Strength, Psi	Increase, Psi
176	21,600	7,800
302	22,200	8,400
572	19,800	6,000

Table II. Annealing vs. Irradiation[6] of Pure Iron

Condition	Lower Yield Strength, Psi
Unirradiated	15,900
Irradiated 27.7 days at 176°F	22,100
Irradiated 27.7 days at 176°F and annealed 14 days at 572°F	18,200
Irradiated 27.7 days at 572°F	20,600

Table III. Effect of Irradiation Temperature on Property Changes[7] of A-212-B Steel

Irradiation	Yield Stress, Psi	Tensile Strength, Psi	Pct R.A.	Uniform Elongation, Pct
None	50,000	75,000	64	22
10^{19} nvt at 140°F	65,400	80,800	68	18
10^{19} nvt at 570°F	56,800	83,900	57	12

The effect of irradiation temperature on yield strength is illustrated in Table I for an exposure of 10^{17} nvt (fast). It is evident that increasing irradiation temperature from 176° to 572°F has only a slight effect in reducing the effect on yield strength at the rather small integrated exposure concerned. There has been considerable interest in simulating irradiation effects at elevated temperature by annealing at the elevated temperature, after irradiation at a lower temperature. The data for iron shown in Table II indicates that there is no such direct relationship. Irradiation at 572°F produced a larger change in yield strength than did annealing for 14 days at 572°F following irradiation at 176°F. It is generally expected that property changes are smaller after irradiation at an elevated temperature for a given time than they would be after annealing at the same temperature and time, having received the same irradiation dose at a lower temperature. However, the lower temperature should be low enough to eliminate, in large measure, any thermally-activated annealing process, and should therefore be much less than the 176°F that was employed in the above example.

Post-irradiation annealing experiments[6] show that the activation energy for attenuation of irradiation-induced increases in yield stress is identical to that for self-diffusion in iron (3.1 ev).

The hardness and electrical resistivity of iron as a function of integrated fast flux is shown in Fig. 3[8]. The hardness changes appear to saturate at about 10^{19} nvt, while electrical resistivity appears to pass through a maximum at the same exposure.

. . . in carbon steels

Most of the work done on low-alloy steels has been on the grades suitable for application as reactor pressure vessels. The tensile properties of ASTM Specification A-212 Grade B carbon-silicon steel are

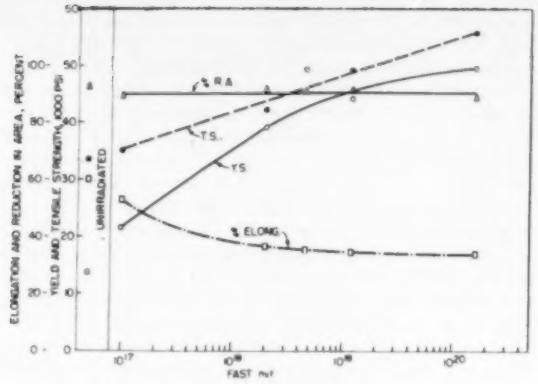

Fig. 1—Effect of neutron radiation at 80°C on room-temperature properties of iron.

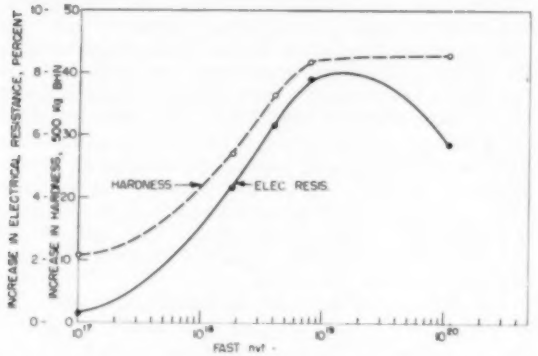

Fig. 3—Effect of neutron radiation at 80°C on hardness and electrical resistance of iron.

markedly affected by irradiation as shown in Fig. 4, taken from the work of Wilson and Berggren[7]. The steel (0.24 pct C, 0.81 pct Mn, 0.020 pct P, and 0.040 pct S, and 0.25 pct Si with ASTM grain size 5) used was normalized from 1900°F and irradiated at a temperature less than 200°F. Yield and tensile strength increased with increasing exposure, and it is probable that further irradiation beyond 10^{20} nvt (fast) would produce further increases. Reduction in area and uniform elongation both decreased markedly upon irradiation. In this respect, the carbon steels are more sensitive to irradiation than are the stainless steels.

The stress-strain curves for the irradiated steel show an abrupt start of plastic deformation with a very small work-hardening rate, followed by an increased work-hardening rate up to the maximum load, as in curve B in Fig. 6. Irradiation appears to reduce uniform elongation until there is practically no elongation at about 10^{20} nvt, so that yielding and the onset of necking almost coincide.

The effect of irradiation temperature shown in Table III is interesting in that it shows that increasing the temperature of irradiation affects the various properties differently. While the increase in yield strength was not as great when irradiated at the higher temperature, the increase in tensile strength was greater. Ductility appears to be more adversely affected by irradiation at 570°F than at 140°F.

The effect of irradiation on notch-impact behavior is more marked than on tensile properties. As shown in Fig. 4, the notched-bar (sub-sized Izod) impact

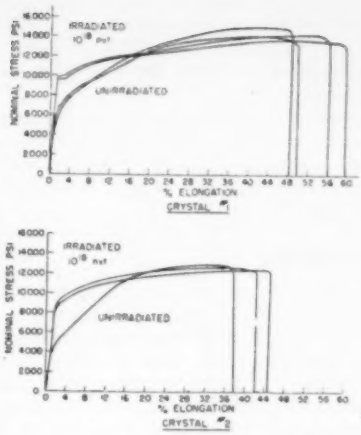

Fig. 2—Effect of irradiation on mechanical properties of pure-iron single crystals.

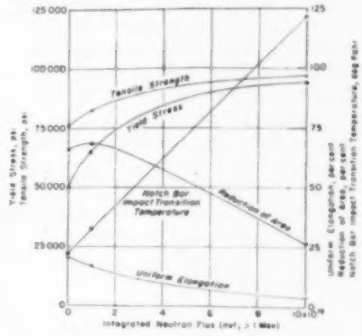

Fig. 4—Integrated fast-neutron flux dependence of several mechanical properties of A-212B carbon-silicon steel.

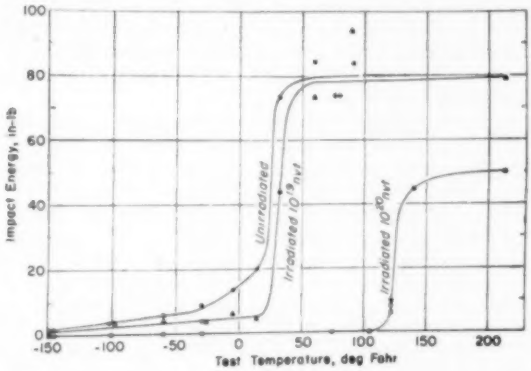

Fig. 5—Effect of irradiation on impact energy curve of A-212B carbon-silicon steel.

transition temperature is increased from about 25°F to 125°F by an exposure of 10^{20} nvt (fast). The increase is apparently linear with integrated flux, and further irradiation would be expected to raise the transition temperature. Impact data shown in Fig. 5, seem to indicate that, in addition to raising the transition temperature, neutron irradiation lowers the impact energy at all temperatures. Similar results are reported by Leeser and Deily[8] for a A-212 steel . . . the heat-affected zone of welds in this steel, E6030 as-deposited weld metal . . . A-70 boiler steel . . . and aluminum-treated steel with 0.34 pct C.

The effect of irradiation to 10^{18} nvt (fast) at 70° to 140°F on the fatigue strength of normalized ASTM A-212 boiler steel is reported by Leeser[9]. In the unnotched condition, the endurance limit (10^7 cycles) decreases from an initial value of 48,000 psi

to 42,000 psi for irradiated material. In the notched condition, the endurance limit increased from 28,000 psi to 35,000 psi on irradiation, the ratio of endurance limits, unnotched to notched, decreasing from 1.7 to 1.2 on irradiation.

Whether or not there are microstructural changes caused by irradiation in carbon steels is a question yet to be settled, although Bruch, McHugh, and Doig[10] reported no change in grain size in iron irradiated 2 to 7 x 10^{19} nvt (fast).

. . . in stainless steels

Stainless steels, particularly the austenitic grades, have found widespread use in nuclear applications, such as pressure piping, pressure vessels, pressure-vessel lining, thermal shields, and fuel-element cladding, largely because of their corrosion-resistant properties. The most interesting feature of irradiation effects in these steels is the introduction of a yielding phenomenon. This is illustrated in Fig. 6 by the stress-strain curves for irradiated and non-irradiated Type 347 stainless steel, taken from the work of Wilson and Berggren[7]. The yield strength is increased from 37,000 to 96,500 psi as a result of irradiation to 7.8 x 10^{19} nvt (fast) at less than 200°F. The yielding phenomenon is evident in curve C, and its dependence on strain rate may be seen by comparing curves B and C. Type 304 ELC (extra-low-carbon) stainless steel also exhibits a yielding phenomenon when irradiated, while Types 301, 302, 302B, 305, and 321 do not. In all cases work-hardening ability is decreased.

Yield stress as a function of integrated fast flux is shown for several of these steels in Fig. 7[7]. The corresponding ultimate strengths changed from 5 to 7 pct. Ductility changes were relatively minor except in the case of Type 347, in which reduction of area decreased from 71 to 62 pct, and uniform elongation decreased from 49 to 25 pct.

A more complete picture of the effect of irradiation at 176°F on the tensile properties of Type 347 stainless steel[8] is shown in Fig. 8; it is to be noted that total elongation is reported. Qualitatively, similar results were obtained by Murphy and Paine[12] for notched tensile strength of Type 347 stainless steel irradiated at about 491°F. Bruch and McHugh[5] report less effect on yield stress after irradiation at 572°F than after irradiation at 176°F, but with an integrated fast flux of 10^{19}; the increase being from 55,000 psi to about 68,000 psi in the former case, and from 55,000 psi to 85,000 psi in the latter.

Post-irradiation annealing experiments[13] indicate that damage in Type 347 stainless steel begins to anneal out between 392° and 752°F, and at 1112°F almost complete annealing occurs.

Bruch and McHugh[5] also determined the effect of irradiation on the tensile properties of Type 347 stainless steel as a function of prior cold work (7, 17, 37, and 58 pct). The properties of cold-worked material behave very much like those shown for annealed material in Fig. 8, except that there appears to be no change in strength or ductility after about 10^{19} nvt (fast) in the materials cold worked more than 7 pct. Similar indications of saturation of notch-tensile strength of cold-worked Type 347 stainless steel at about 10^{20} nvt were found by Murphy and Paine[11] for material irradiated at about 491°F.

The fatigue strength of Type 304 stainless steel in both the notched and unnotched condition is not affected by irradiation to 10^{19} nvt (fast) at 70° to 140°F[9]. Notch-impact tests performed by Wilson and Berggren on Type 347 and by Leeser on Type 347 and 304 after irradiations of 10^{19} to 10^{20} nvt (fast) reveal no indications of brittle behavior.

That structural changes can occur with irradiation of austenitic stainless steel is demonstrated by the work of Reynolds, Low, and Sullivan[12] and Leeser[13]. Below about 752°F, austenite is thermodynamically unstable, and small amounts of ferrite can be made to appear by cold working. The effect of neutron irradiation upon the stability of austenite in Type 347 stainless steel as determined by Reynolds *et al* is shown in Fig. 9 as a function of neutron exposure and amount of prior cold work. Neutron irradiation causes a small increase in the amount of ferrite present, the increase being larger the greater the exposure and the greater the amount of prior cold work. Irradiation appears to promote the growth of existing ferrite rather than to induce new nuclei. This result is explicable on the basis of the action of displacement spikes at ferrite-austenite boundaries, the existing ferrite serving as a locus for coherent nucleation of additional ferrite upon quenching of the spike. Leeser reported that the magnetic susceptibility of Types 304, 309, 316, 347, 431, and 442, and Armco 17-4 PH and USS Type "W" increases after an exposure of 1 to 3 x 10^{19} nvt (thermal—fast flux not given). In all cases, the amount of ferrite produced is small. Type 309 showed the smallest effect, presumably because the austenite in this alloy is more stable than in the others. The ferritic and precipitation-hardening alloys showed smaller changes than the 18-8 steels.

The effect of irradiation on the tensile properties of Type 410 stainless steel as determined by Robinson[14] is shown in Fig. 10. The material, initially oil-quenched after 30 min at 1800°F and then tempered for 30 min at 1000°F, was exposed in the Materials Testing Reactor (MTR) process water (~104°F) to an integrated fast flux of 3.3 x 10^{20} nvt. The property changes are comparable to those found for the 300-series stainless steels.

Conclusions

In ferrous materials, as in other metals and alloys, irradiation increases strength and decreases ductility. In general, the yield stress is increased proportionately more than the ultimate stress, accompanied by a reduced strain-hardening capacity and decreased uniform elongation. In the stainless steels, there appears to be no cause for alarm in that the property changes generally appear to saturate at a total exposure of 10^{19} or 10^{20} nvt. In the carbon steels, the rise in ductile-brittle transition temperature and the loss of elongation and reduction in area are of concern, and further work in extending the data to higher neutron exposures, particularly at elevated irradiation temperatures, is required in order to provide a basis for the use of these steels in the more severe applications.

There is an absence of in-pile creep data for steels. However, this does not appear to pose a problem since in-pile creep studies on several other materials indicate that the creep rate is reduced as might be anticipated from the general nature of the effects on strength properties.

Irradiation-induced structural changes in steels have received little attention thus far. Structural effects observed in nonferrous systems and in fissionable materials strongly suggest that such effects might be found in ferrous materials, particularly in

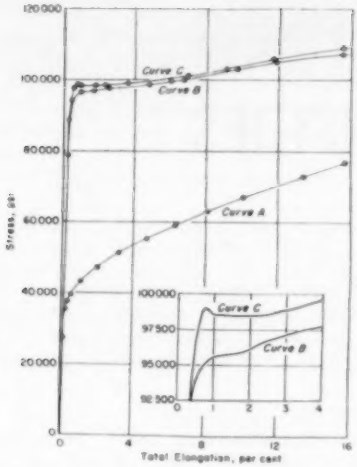

Fig. 6—Tension stress-strain curves for annealed austenitic 347 stainless steel. A—Un-irradiated metal; strain rates of 0.01 and 0.05 in. per in. per min (two tests). B—Irradiated metal (7.8 x 10^{19} nvt); strain rate 0.01 in. per in. per min. Note region of low work hardening. C—Irradiated as before; strain rate 0.05 in. per in. per min. Note "yield point" and yield point elongation.

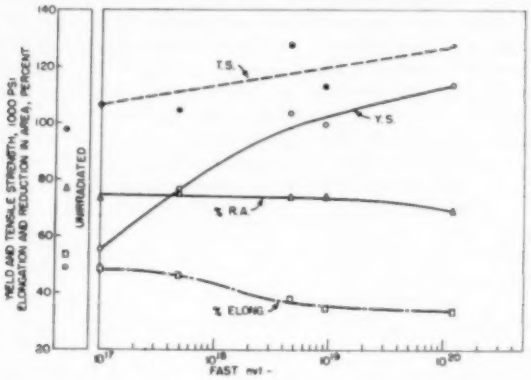

Fig. 8—Effect of neutron radiation at 80°C on the room-temperature tensile properties of annealed 347 stainless steel.

those which are irradiated in a non-equilibrium condition at the temperature of irradiation. The effect of initial structure upon irradiation-induced property changes does not appear to have been explored. The well-known response of steels to heat treatment provides a ready basis for experimentation of this kind which may well yield fruitful results. There is no reason why conventional heat treatment should necessarily provide optimum irradiation behavior.

While no attempt was made to present an exhaustive recapitulation of the literature on the subject, it is hoped that the selection of illustrative data has served adequately to present a picture of the behavior of steels under irradiation.

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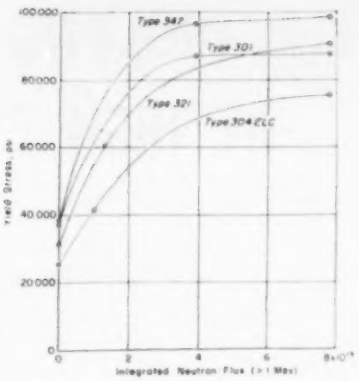

Fig. 7—Effect of integrated fast-neutron flux on yield strength (0.2 pct offset) of several stainless steels irradiated below 200°F.

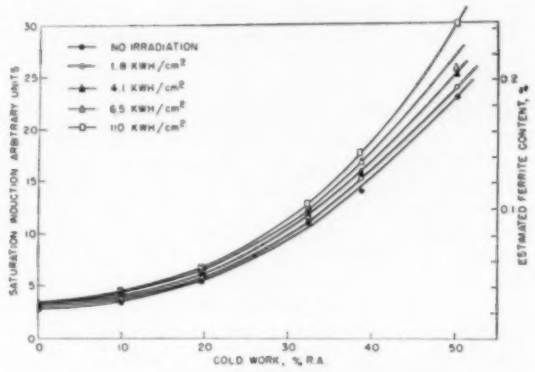

Fig. 9—Effect of irradiation on magnetic saturation induction of 347 stainless steel.

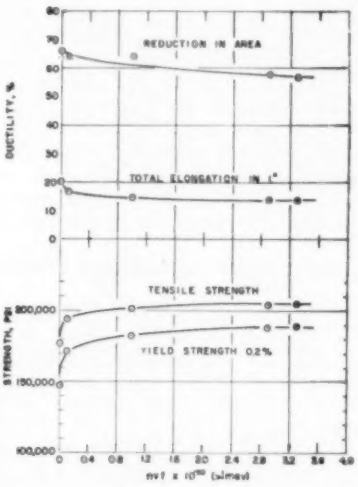

Fig. 10—Effect of irradiation on tensile properties of 410 stainless steel; irradiation carried out in MTR process water.

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ELECTROLYTIC COPPER REFINING AT HIGH CURRENT DENSITIES

Evidence points to the fact that minimum copper refining costs can be achieved at higher current densities than are currently employed. This article describes copper refining experiments conducted at current densities of up to 500 amps per sq m in specially constructed channel cells in Sweden.

by S. J. Wallden, S. T. Henriksson, P. G. Arbstedt, and Th. Miöen

ELECTROLYTIC refining of blister copper by the multiple method is performed in almost the same way throughout the world. For more than 50 years no important changes have been made, and this, of course, indicates that the method has been well suited to its purpose. However, one should not assume that further developments or improvements are impossible. As a matter of fact, it must be admitted that much of the knowledge concerning this method is of an empirical nature, and thus, it seems likely that basic research on electrolytic refining may lead to valuable improvements.

During the last few years, intensified research on the electrolysis of copper has been performed at the Central Laboratory of Bolidens Gruvaktiebolag in Sweden. Part of this work has been to make a systematic investigation of the possibilities in making fundamental technical changes in process and equipment, possibly leading to technical and economic improvements. Studies of the reactions of some electrolysis-interfering elements has comprised another part of the work. One of the investigations concerns copper electrolysis at high current densities—a theme little mentioned in the literature.

Importance of current density

Economics of the process

Upon increasing the current density, certain costs (calculated per unit of copper produced) will decrease, others increase, and some remain unchanged. Costs dependent on current density are, mainly, those for:

a) **Power consumption:** This cost, per unit copper deposited, is almost directly proportional to the current density.

b) **Steam consumption:** If the input of electrical energy is increased, the main part of this increase will be converted into heat in the electrolyzers, this internal heat replacing heat provided by externally supplied steam. Since the electrical energy is converted directly into heat in the electrolyte due to its ohmic resistance, a 100 pct efficiency is obtained, i.e., much higher than that obtained when heating with steam. The steam cost, thus, decreases with increasing curent density, and the combined cost for power and steam may either increase or decrease with increasing current density—depending on the relationship between power and steam prices.

c) **Loss of interest on capital:** At a constant production of copper and an unchanged tank size, the number of tanks is inversely proportional to the current density. The loss of interest on capital bound in the process in the form of copper in the anodes, cathodes, and electrolyte, and in the form of noble metals in the anodes and anode slime will, therefore, decrease with increasing current density.

d) **Loss of noble metals to the cathode:** According to Addicks[2] and in our own experience, the gold and silver contents in the cathodes increase with increasing current density, thus resulting in an economic loss.

e) **The electrolysis plant:** The capital cost of an electrolysis plant is, of course, dependent on the current density. The degree of dependence, when the current density increases, is difficult to predict, since such a step would undoubtedly necessitate many radical changes in the construction and equipment of the plant. Benefit in the form of decreased number of tanks, reduced plant area, and somewhat smaller quantities of construction metals would probably be counteracted by a more expensive construction and costs of additional electrical equipment needed for higher current densities. Only that part of the plant area containing the electrolysis tanks is current-density dependent. The remainder, just as the needed auxiliary machines and other apparatus, is almost completely independent. Any decided reduction in plant costs, therefore, can not be expected from an increase in current density.

f) **Operating costs and labor:** The costs of running the plant and for labor required are affected by the current density. However, it is impossible to predict the effect of an appreciable increase of the current density, for the same reasons given under the discussion of capital costs.

For a more detailed study of current density's influence on the economics of electrolytic copper refining, we suggest a work by Hoffman-Schiffner.[3]

Purity of the cathode copper

A detailed discussion of the influence of current density on purity of copper produced will not be undertaken here. Only a few difficulties which can

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be expected to occur when the current density is greatly increased will be mentioned.

First, it is expected that there may be an increased electrolytic deposition of those impurities which, even at normal current densities, may be deposited. This particularly applies to bismuth and —although this is uncertain—also to antimony and arsenic.[4]

In addition, an increase in the current density results in a more uneven cathode surface. This can cause an increased occlusion of any anode slime that is stirred up during the electrolysis, and can produce a consequent increase in the impurity content of the cathode. The influence of the current density on the gold and silver contents in the cathode has been mentioned above.

If the current density exceeds a certain limiting value, then the copper is no longer deposited in a coherent form but as a powder, because of the impoverishment of the Cu^{2+} in the cathode film.

Cathodic current efficiency

With increased current density but otherwise constant electrolysis conditions, decrease in current efficiency due to the aerial oxygen dissolved in the electrolyte becomes of relatively smaller importance. One can, on the other hand, expect an increased tendency toward short circuiting with an accompanying decrease in the current efficiency.

As soon as the limiting current density is exceeded, a considerable decrease in the current efficiency is obtained with respect to the deposition of copper, because hydrogen begins to be evolved at the cathode.

Anode reactions

One of the difficulties which can be expected upon increasing the current density is the increased risk for passivation of the anodes. Even at normal current densities, such troubles occur now and again. The reasons are not yet completely known. It is clear, however, that the possibility of passivity occurring will increase with increasing current density and that the resulting increase in the Cu^{2+} and Ni^{2+} concentrations in the anode film play some part in this complicated process.

Aim of this investigation

As stated above, an increase in the current density results in an increase of certain costs per unit of copper produced, and a decrease in others. There probably exists a definite current density for which the sum of these current-density-dependent costs have a minimum. Considerable evidence points to the fact that this value lies high above current densities used at present. How much higher depends not only on the variation in price of copper, steam, electrical energy, rate of interest, and so on, but more particularly on what solution can be found for the technical problem of producing satisfactory electrolytic copper with a high current efficiency at much higher current densities—without the occurrence of disturbing anode reactions. Therefore, the aim of the work was to find a practically applicable solution of the purely technical part of the problem.

It is generally agreed that most of the difficulties occurring at high current densities arise from the Cu^{2+}-impoverishment of the cathode film and the Cu^{2+}-enrichment of the anode film. These troubles could be eliminated if the mass transfer through the diffusion boundary layers (the electrode films) at the cathode and the anode could be facilitated to a sufficiently great extent. The method considered the most practical one for this purpose was the one in which a considerable increase is made in the relative motion of the electrolyte and the electrodes. In this way, the diffusion distance is shortened and the concentration gradient increased to a considerable extent.

Neither the idea of improving the economies of electrolytic copper refining by using a higher current density, nor the principles of the methods for carrying it out are new. Suggestions and a certain amount of research have led to applications for patents. However, none of the suggested methods has, as far as is known, been used for the electrolytic refining of copper on a large scale—at least not at such high current densities as 400 amps per sq m. The reason for this is probably not that there is anything wrong with the idea as such, but rather that the technical application of the idea has been made far too complicated.

Results of laboratory experiments

The rapid relative motion of the electrolyte and the electrodes, which is necessary at high current densities, can in principle be accomplished in two different ways, viz, by moving either the electrodes or the electrolyte.

Experiments with rotating and vibrating cathodes

The use of a rotating cathode satisfies the demand for a rapid motion relative to the electrolyte and should, therefore, make possible the electrolytic refining of copper at very high current densities.

This method has been investigated in a series of experiments using a cathode (consisting of a rotating copper cylinder) which was situated between plane anodes of blister copper. The anodic current density was 40 pct of the cathodic. The experiments were performed at 65°C with normal plant electro-

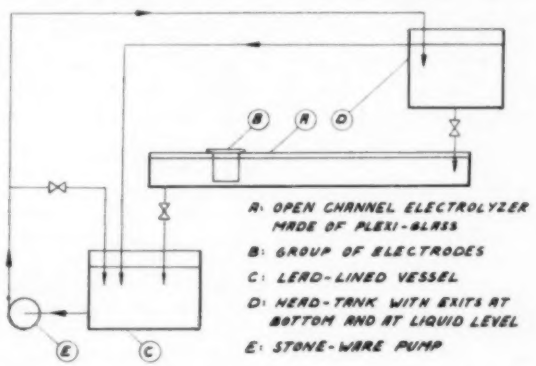

Fig. 1—Flowsheet of the laboratory-scale moving electrolyte channel.

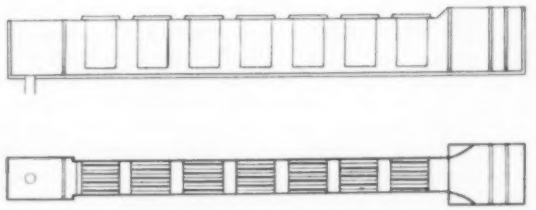

Fig. 2—Pilot-plant channel electrolyzer.

lyte. The results can be summarized as follows:

a) Using peripheral velocities on the order of 10 m per min, it was possible to produce a coherent copper cathode with approximately 95 pct current efficiency—even at such high current densities as 6000 amps per sq m. However, copper produced contained considerable amounts of arsenic, antimony, and especially bismuth.

b) Cathodic copper which was satisfactory in respect to both appearance and impurity content could be prepared using current densities up to about 1000 amps per sq m.

c) In order to avoid the occlusion of stirred-up anode slime in the cathode, it was necessary to surround either the anodes or the cathodes with some sort of diaphragm. This diaphragm, it was found, must be sufficiently porous—otherwise a Cu^{2+}-impoverishment of the catholyte occurs, with resulting deterioration not only in the surface properties and quality of the copper cathode but also in the current efficiency.

d) Since only the cathode was kept in motion, there occurred—as expected—difficulties due to anodic passivity.

Similar results were obtained in experiments with a vibrating cathode. A parallelepipedic cell was divided into two anodic and one cathodic section by means of two diaphragms. The cathode was attached to one end of a thick copper wire; the other end was fixed to the plate of a vibrator. Also, with this method it was possible to produce acceptable copper at current densities as high as 1000 amps per sq m.

However, neither of these methods for producing the necessary relatively rapid motion of the electrodes and the electrolyte can be considered to be economically applicable on a technical scale. In the case of the rotating cathode, the occurrence of movable parts in such a strongly corroding atmosphere constitutes a great disadvantage both from the mechanical as well as the electrical point of view. Because of the risk for passivation of the anodes, it is not sufficient to rotate or vibrate only the cathodes; this must be done also with the anodes. The necessity of using diaphragms for eliminating the occlusion of slime in the cathodes also constitutes a considerable disadvantage.

Experiments with a moving electrolyte

The possibility of developing a technically applicable method for electrolysis at high current densities in which the electrolyte is made to flow at high speed parallel to the electrodes seemed more promising. This method possesses great advantage in that improvement in the ionic diffusion is obtained at both the anodes and the cathodes. However, since the use of diaphragms was considered to complicate the cell construction far too much, it was considered necessary to solve the problem concerning the cathodic occlusion of the stirred-up anode slime in some other way. The question was whether the rapid flow of electrolyte along the cathode surface might be sufficient to keep it free from slime particles. This idea is, in principle, not new. For example, in a patent of 1913[3], an arrangement was described whereby the cathode surfaces were washed by leading the circulating electrolyte into the cell by means of tubes whose outlets were placed close to the edges of the cathodes. However, such a solution of the problem seems to be far too complicated for use on a large scale. This was, in fact, apparent when trials were made with an arrangement of this type.

Table I. Typical Analysis of Electrolyte and Anodes at Boliden's Copper Refining Plant

Electrolyte, gpl			
Cu	50	As	2-3
H_2SO_4	170	Sb	0.5-0.6
Ni	15	Bi	0.2-0.3
		Cl	0.04

Anodes, pct			
Ag	0.15	Sb	0.03
Au	0.01	Bi	0.010
As	0.10	Se	0.10

It was thought that an easier method for producing the desired relative motion was to make the electrolyte flow through a channel—with the electrode surfaces placed parallel to the direction of flow. This idea was first tested on a laboratory scale using a channel of plexiglass 600 mm long, 100 mm deep, and 75 mm wide, situated as shown in Fig. 1. An electrode *packet* consisting of two anodes (normal blister copper) and three cathodes was suspended in the channel parallel to the direction of flow. The results of these experiments can be summarized as follows:

a) A satisfactory cathode copper could be prepared with current densities up to around 1000 amps per sq m and without the use of diaphragms—provided the electrolyte flow rate relative to the electrodes was at least 3 to 4 m per min and the slime content was not allowed to exceed 20 to 30 mg per l. This latter condition was satisfied by means of a completely separate, continuous filtration of the electrolyte.

b) If the condition in (a) for the flow rate was satisfied, then no anodic passivity occurred.

c) If the current density was decreased to 500 amps per sq m, then it was possible, at a flow rate of 4 m per min, to allow considerably greater slime contents than 20 to 30 mg per l in the electrolyte without having the copper cathode affected by slime occlusion.

Experiments with channel electrolyzers

The success of experiments with plexiglass channel encouraged similar experiments on a larger scale. However, it should be mentioned, at this point, that this idea of a suitable cell for electrolysis at high current densities has been published earlier in two US patents[4]. The arrangement described in them differs considerably from the one used in this investigation, however. The older patent differs from our arrangement mainly insofar as the connection of the electrodes is concerned; the newer one—which is stated to be a development of the older one—differs in the manner in which the electrolyte is circulated. In neither of the patents is detail given about the current density, flow rate and so on, and, as far as can be judged, it seems that the method has never been applied in practice.

Advantages of a channel-shaped electrolysis cell

The advantages, which the use of a channel-shaped electrolysis cell offers and which motivated our choice of this type of cell for research work on electrolysis at high current densities, are as follows:

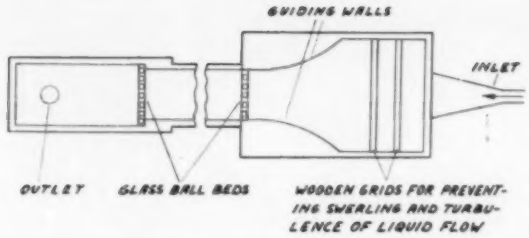

Fig. 3—Detail of the inlet and outlet of the pilot-plant electrolyzer.

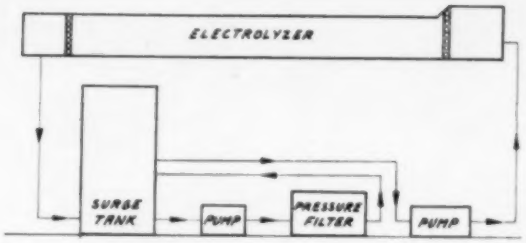

Fig. 4—Simplified flowsheet of the pilot plant.

Fig. 5—Arrangement of the electrodes.

a) This method is undoubtedly the easiest way of obtaining a rapid relative motion of the electrolyte with respect to both he cathodes and the anodes.

b) By increasing the capacity of the pump, it is possible to reach very high circulation rates.

c) The shape of the channel, if combined with a suitably constructed inlet and outlet, produces an even flow of liquid over the whole of the cross section of the cell.

d) From a constructional point of view, a channel is simple and uncomplicated, especially if diaphragms are unnecessary.

e) The placing of the electrodes parallel to the flow of the electrolyte results in the desired improvement of the mass transfer rate.

f) It is possible to connect a large number of *electrode groups* in series, each group consisting of a number of parallel anodes and cathodes. Effective use is, thus, made of the energy used for pumping. With this method for connecting the electrodes, the current will, moreover, be of an acceptable magnitude (=cathode surface area in each group x current density), and the voltage will depend on the number of groups (=group voltage x number of groups). It is not as satisfactory to connect the groups in parallel, since the channel will then have to work at a very large current (=cathode area in each group x current density x number of groups) and low voltage (=cell voltage). In addition, connection in parallel would result in a risk for an unequal sharing of the current between the groups. A disadvantage of connection in series will be discussed below.

Apparatus used in the present work

After a number of preliminary trials, the channel used for semi-industrial scale experiments received the final shape shown schematically in Fig. 2. For experiments on a smaller scale, the channel used was only one-fifth the size of the larger one. However, apart from the lining material (non-flexible PVC), it differed only negligibly from the larger one. The description which follows applies to the larger channel and its auxiliary equipment.

a) **Size:** Length, excluding inlet and outlet, was 7.5 m; total length 11 m, width 0.5 m, and depth 1.0 m.

b) **Construction materials:** The channel was made of wood and was originally lined internally with only a layer of oppanol (polyisobutylene). For reasons which will be given below, it was necessary to place a lead lining over the oppanol layer and then insulate this lead layer by means of a new layer of oppanol.

c) **Inlet and outlet:** The parts making up the inlet and outlet are shown in Fig. 3. The electrolyte was led in through a conical tube fixed to one end of the channel. The inlet chamber was separated from the channel by means of a bed of glass balls. It contained, in addition, two grids and two guiding walls in order to improve the flow of liquid. Thanks to this arrangement, the flow through the channel was laminar and uniformly distributed over the whole of the channel cross section. A similar bed of glass balls was placed between the channel and the outlet in order to further improve the flow of liquid.

d) **Pumping and filtration system:** The pumping and filtration system is shown in Fig. 4. The electrolyte was circulated using an acid-proof pump provided with liquid-sealed packing boxes. It had a capacity of 6000 l per min at a delivery height of 3 m. Satisfactory filtration was obtained by means of a pressure filter equipped with ceramic filtration pipes. The electrolyte was transported to the filter by means of an acid-proof pump with a capacity of ca 300 l per min at a delivery height of 30 m.

e) **Electrodes and their connection:** Full-size anodes (effective dimensions 950x670 mm and weight 180 to 200 kg) and starting sheets of standard type were employed. Every second electrode group contained three anodes and four cathodes connected in parallel while every other group contained four anodes and three cathodes. The channel contained seven such groups altogether, connected in series as shown in Fig. 5.

One of the advantages of this method of connecting the electrodes is that the amount of copper required for the bus bars is slight, since only the first and last bars have to be large enough to carry the full cell current. Contact between groups was made by means of a thin copper bar. On it were supported the cathodes in one group and the anodes in the following group. The distance between the groups was equal to about twice the length of the anode supporting lugs, i.e. 290 mm. A photograph of the channel is shown in Fig. 6.

Experimental conditions

A large number of runs have been made using both the smaller and the larger channel. In all experiments, electrolyte from Boliden's copper electrolysis plant and anodes with normal impurity contents were used; compositions of both are given in Table I. The temperature of the electrolyte was

Table II. Cathode Analyses for Three Trial Runs Using Smaller Channel

D_c, Amp per Sq M	Liquid Velocity, M per Min	Content of Slime in Electrolyte, Mg per L	Time of Run, Hr	Impurities in Cathode Copper, Ppm									
				Ag	As	Bi	Fe	Ni	Pb	Sb	Se	Sn	Te
500	10	260	71	30	1	0, 6	<5	<2	0, 5	8	5	<0, 5	<1
500	10	25	72	10	1	1, 1	<5	<2	0, 5	5		<0, 5	<1
500	10	250	70	30	1	0, 5	<5	<2	1	5	<3	<0, 5	<1

maintained at 65°C and an electrolyte flow rate relative to the elecrodes of 10 to 13 m per min was employed. A mixture of glue, qoulac, and thiocarbamide was used as inhibitor.

Almost all the experiments have been performed at a current density of 500 amps per sq m. The reason why higher current densities have not been used is as follows:

It is possible to show that the amount of energy in the form of steam, which is necessary to maintain the electrolyte at a constant temperature, is

$$S = \frac{P \times 10^5}{1.186 \times \eta\, D_k F} - \frac{10 \times r\, l\, D_k}{1.186 \times \eta} \quad \text{kw-hr per metric ton Cu}$$

where

P = total energy consumption in kw-hr per hr and tank (For a constant electrolyte surface area, this quantity can be considered to be independent of the current density),

D_k = Current density, amp per sq m,
F = total cathode surface area per tank, sq m,
η = current efficiency, pct x 0.01,
r = resistivity of the electrolyte, ohm. cm; and
l = distance from anode to cathode, m.

When $S = 0$, then the whole of the requisite heating energy is supplied electrically. The current density necessary for this would be

$$D_k = \sqrt{\frac{P \times 10^5}{r\, l\, F}} \text{ amps per sq m.}$$

From practical experience, we know that, at 65°C, P/F is about 0.2. For the present case, $r = 1.83$ and $l = 0.035$. Thus

$$D_k = \sqrt{\frac{20000}{1.83 \times 0.035}} = 560 \text{ amps per sq m.}$$

If this value for the current density is exceeded, then the electrolyte must be cooled artificially—something which is in itself, of course, not unfeasible. We have, however, chosen to work at 500 amps per sq m and to supply a small amount of the heat required by means of steam.

The slime content of the electrolyte was kept as low as possible by means of continuous filtration. In some experiments, however, the slime content was allowed to rise to very high values in order to determine how much the slime content could be allowed to increase without affecting the purity of the cathodes seriously.

Results of experiments with the smaller channel

In Table II, the cathode analyses for three of the trial runs using the smaller channel are shown. It is seen that the contents of impurities in the cathodic copper were mostly low; however, the antimony and, in particular, silver contents were greater than those in electrolytic copper produced from the same sort of raw copper using a normal current density in a conventional cell.

In some experiments, the slime content in the electrolyte was as high as 280 mg per l, but no appreciable occlusion of slime particles occurred. This is shown by the fact that the selenium contents were <3 g per ton. Therefore, the high silver contents obtained could not have been caused by occluded slime. In addition, we have found that the silver in this particular slime occurs completely as CuAgSe. Hence, a high silver content due to slime occlusion should have resulted in a higher selenium content than was actually the case. However, we have found that electrolyte containing dissolved air can extract silver from the anode slime and that this silver is deposited electrolytically on the cathodes whether the electrolyte contains chloride ions or not. This explains the relatively high silver contents in the cathodes.

Cathodes were very even and coherent but possessed large outgrowths at one edge (Fig. 7). These excrescences are caused by the leakage of current from group to group due to the difference in voltage among them. Because of this leakage, one edge of the cathodes grows much thicker than the other. In order to get the thicker one as coherent and even as possible, it is necessary to have the potential drop in the same direction as the flow of electrolyte.

The magnitude of this current leakage is, of course, dependent on the voltage difference among the groups. In these experiments, no special precautions were taken to keep this leakage at a minimum—the groups were connected by rather long connecting cables. The voltage difference was, therefore, as high as 0.28 v, and this resulted in a relatively low current efficiency (0.84 pct), as well as the edge outgrowths mentioned above. As will be shown below, this disadvantage of connection in series can be completely eliminated if the electrode contacts are given a suitable arrangement.

The cell voltage was 0.40 v at 500 amps per sq m and the anode-cathode distance 35 mm. Anode passivation did not occur when the flow rate was 10 m per min. However, if the flow rate was reduced to 5 m per min, passivation occurred frequently.

Results in the semi-industrial-scale channel

In the experiments with the semi-scale plant, the cathode surface area in each group was 4.4 sq m (sum of six cathode surfaces). For a current density of 500 amps per sq m, the total current was therefore 2200 amps. In most of the experiments seven such groups were connected in series. The distance between the groups was 290 mm.

The electrolyte—usual plant electrolyte—was circulated at a rate relative to the electrodes of 13 m per min. This corresponds to 6000 l per min.

Fig. 6—Electrolysis channel in the pilot plant.

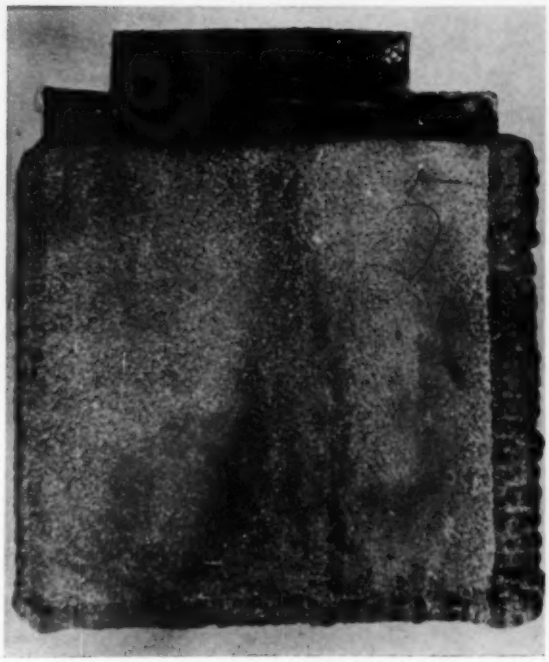

Fig. 7—Right, cathode from the smaller channel, showing an even and coherent deposit except for the large outgrowth on the right edge, due to leakage of current from group to group.

In order to remove slime from the electrolyte, about 300 l of electrolyte per min was taken from the main circulation system and forced through the pressure filter.

The anodes and starting sheets were of the usual standard type. The anode-cathode distance was 35 mm.

The results of these experiments can be summarized as follows:

a) **Shape of the channel and liquid flow:** The shape of the channel with respect to the flow of the liquid has been found to be quite satisfactory. Over the whole of the cross section, the flow was laminar and evenly spread without any sign of vortex formation. This proved to be of great importance as far as the avoidance of air bubbles in the electrolyte was concerned. If air bubbles become attached to the cathode surface, they cause much trouble due to pitting, and so on.

b) **Channel construction materials:** The channel is made of wood and was originally lined internally with only a layer of oppanol. However, this lining eventually developed cracks. The channel was, therefore, lined with lead over the oppanol and the lead layer was insulated electrically from the electrolyte by means of a new layer of oppanol. This last step is important because of the large potential difference between the ends of the channel. When electrolysing seven electrode groups simultaneously, this potential drop was as much as 3 to 4 v. Without this insulation, the lead lining would act as an intermediate conductor.

However, the combination of wood, lead, and oppanol has not proved satisfactory. Cracks developed in both the lead and the oppanol. This is probably due to the stresses set up in the channel because of the differing expansion coefficients of the construction materials. Moreover, the destructive effect of such stresses was particularly great in this case because of the intermittent use of the channel. We believe that rubberized iron plate or concrete lined with ceramic plates or plastic material would be more suitable.

c) **Connections, current, current efficiency:** Connection in series has the advantage that the current required is of a reasonable magnitude. However, it has the disadvantage already mentioned of current leakages between groups. Thanks to the direct cathode-anode contacts, though, the potential drop between the groups has been kept below 0.1 v and, thus, the current leakages have been small. The current efficiency has, therefore, been 90 to 92 pct and the edge excrescences almost negligible.

d) **Cell voltage, energy consumption:** At 500 amps per sq m, the potential difference between anode and cathode was 0.48 v. The potential drop in one group was:

positive bus bar—anode	0.014 v
anode—cathode sheet	0.476 v
cathode sheet—cathode loop	—
cathode loop—rod	0.007 v
rod—negative bus bar	0.027 v
Total	0.524 v

The energy consumption amounted to about 500 kw-hr per metric ton copper. In this figure, the energy used for pumping has not been included; however, this should be of relatively small importance when going over to full scale production, since the number of electrode groups can be made very large without altering the electrolyte volume circulated per unit of time. The latter is determined

Table III. Typical Cathode Analysis from Semi-Industrial-Scale Channel

Impurities, ppm			
Ag	38	Sb	3
As	3	Se	17
Bi	1.2	Sn	<0.5
Ni	3	Te	<1
Pb	3		

Table IV. Theoretical Relationship Between Current Density and Energy Consumption in Copper Refining

D_c, Amps per Sq M	Energy Consumption, Kw-Hr per Metric Ton Cu		
	Electric	Steam	Total
235	300	590	890
350	420	280	700
500	580	50	630

only by the cross sectional area of the channel and the flow rate. The increased pressure drop encountered upon increasing the length of the channel is negligible.

e) **Slime removal:** Thanks to the rapid flow of electrolyte, the slime which had become loosened from the anodes was transported out of the cell and removed by the filter. Only a negligible amount of the slime was left lying on the bottom of the channel. In general, slime removal was quite satisfactory, and it has been possible to keep the slime content of the electrolyte down to or below 50 mg per l.

f) **Appearance and impurity content of cathodes:** One characteristic phenomenon which occurred in almost all trial runs with the semi-industrial-scale plant was a sudden deterioration in the cathode surface after about 48 hr, i.e. about half the time for which the cathode was allowed to grow in the cell. After having remained smooth and even, the surface suddenly became as rough as sandpaper. Slime and even air bubbles eventually became attached to such a rough surface, thus resulting in a further deterioration of the surface and a corresponding increase in the impurity content. Experiments in the smaller channel, in which this phenomenon did not occur, showed that, if the cathode surface could be kept smooth and even, the impurity content would be much smaller.

The reasons for this phenomenon are not yet known, although certain observations indicate that it either depends upon a periodic occurrence of a certain slime in the electrolyte containing arsenic-antimony-bismuth (a so-called floating slime) or a depletion of the inhibitor in the electrolyte. The latter could be due to a colloidal absorption in the slime layer of the filter. Solving this problem is essential.

The largest quantities of impurities are arsenic, antimony, and bismuth (caused possibly by the formation of floating slime), but silver and selenium (caused mainly by the occlusion of anode slime on the rough cathode surface, but partly by electrolytic deposition of silver) are also found.

In order to avoid a high content of selenium and silver in the copper, it is of great importance that the cathode surface should be kept smooth during the whole cathode cycle. As an example of a cathode analysis which is typical for the method in its present form, we can cite Table III.

A comparison of the selenium content obtained in this case with the contents obtained using the smaller channel (see Table II) shows the importance of a smooth cathode surface for the avoidance of slime occlusion. A comparison with commercial electrolytic copper produced from similar anode copper shows about the same level of impurity contents, except for the silver and selenium contents (6 ppm and <3 ppm respectively).

g) **Anode reactions:** The anodes dissolved very evenly, and the percentage of anode residues was small. No sign of anode passivation was observed.

Technical conclusions

The investigations have shown that it might be technically possible to electrolyze anode copper with high impurity contents at current densities far above those used in the industry today. Problems remain to be solved, however, as to the control of the impurity contents of the cathode copper. The dissolution and electrolytic precipitation of traces of silver is one such problem, and the maintenance of a smooth cathode surface during a whole cathode cycle in order to avoid contamination with anode slime is another.

The electrolysis at high current densities requires equipment that is much different from the conventional. In some respects electrolyzing in big channel units seems to offer possibilities for economies. The continuous transport of the anode slime from the channel to the filtering unit is labor saving, and the central control of the electrolyte flow to a lot of electrode groups in series also saves labor. The tubing system is simplified and will require less maintenance. On the other hand, pumping capacity must be much higher, even if the channels are made very long, and consequently the power consumption for pumping will be correspondingly higher.

Although investigations have been made in a channel with seven small groups of full size electrodes, we do not expect any important complications in increasing the number of electrodes in the groups and the number of groups in series. It is evident that, if the advantages of the channel are to be exploited, the number of electrode groups in a unit should be fairly large. We have considered about 30 electrode groups and a channel length of about 45 m. We have also considered a current strength of about 20,000 amps and a channel width of about 3 m and depth of about 1.2 m.

Economic considerations

The investigation does not permit any definite evaluation of the economic possibilities of applying high current densities to electrolytic copper refining. It is evident, however, that the cost factors necessarily dependent on current density will be of dominating importance. Other cost factors, which are less current-density dependent, probably do not influence the calculations in the same degree.

The importance of the current density for the power, steam, and total energy consumption is illustrated in Table IV (theoretical calculations based on an example of practical figures for the lower current density). The local power and steam prices will determine how the total energy costs vary with the current density.

The importance of the interest on process metals is evident from the fact that the bound metal quantity is inversely proportional to the current density. This quantity in a plant working at 200 amps per sq m amounts to about 65 metric tons metals (all metals counted as copper) per 1000 tons produced copper per year.

To be able to estimate the costs of labor, repairs, and so on, and the amortization and interest on investments, a complete projecting of a full-scale plant for high current density has to be made. However, referring to the previous discussions, it seems that electrolysis in big units gives possibilities of a certain rationalization.

Consideration must also be taken of the economic importance of the copper quality and of the losses of noble metals to the cathodes.

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METALLURGICAL SOCIETY OF AIME

NEWS

Nonferrous Metallurgists to Sponsor First Program at This Year's Fall Meeting

This year's Fall Meeting of The Metallurgical Society will offer two sessions on *Current Practices in the Melting and Casting of Nonferrous Alloys.*

For the first time, the Non-Ferrous Metallurgy Committee of the Institute of Metals Division will sponsor a portion of the program. As a starting point, the Committee has, appropriately enough, organized the session from the viewpoint of the nonferrous physical metallurgist.

Scheduled for Thursday, Nov. 5th, the program is, as yet, incomplete, however, it tentatively includes: *Gas and Its Control in the Casting of Aluminum,* Donald La Velle, research metallurgist, American Smelting & Refining Co.; *Current Practices in the Melting and Casting of Zinc,* J. M. Buchanan, asst. supt. of the Zinc dept., Consolidated Mining & Smelting Co. of Canada, Ltd.; and *Current Practices in the Melting and Casting of Copper Alloys,* P. H. Kirby, asst. technical mgr., The American Brass Co.

The Nonferrous Metallurgy Committee's part of the program will be the result of *sounding out* metallurgists in the nonferrous metals industries themselves, and will be "in line with their preferences," explains F. H. Wilson, Committee chairman.

This Fall Meeting will also feature a full program dealing with both physical and extractive metallurgy. The Division's Committee on the Chemistry and Physics of Metals will hold two sessions during the Nov. 2-5 Meeting at the Hotel Morrison in Chicago.

The Refractory Metals Committee has planned two sessions for Monday, Nov. 2nd on the *Preparation of Refractory Metals and Their Properties.*

Tuesday, Nov. 3rd will witness two Extractive Metallurgy Division meetings: sessions on the *Extractive Metallurgy of Refractory Metals* and the *Refining of Pure Metals.* They will supplement the IMD's program that day. The Iron and Steel Division has also set aside two sessions on Tuesday for papers on current developments in steelmaking. Also scheduled for that day is the Titanium Committee's annual symposium on titanium developments. Rounding out the full day will be the Annual Fellowship dinner.

Wednesday, Nov. 4th, the Nuclear Metallurgy Committee will feature an all-day symposium on the *Effects of Irradiation on Fuels and Fuel Elements.* Topics to be covered include the effects radiation has on such materials as uranium carbide, uranium nitride, and UO_2 fuel elements. Swelling and fission-gas agglomeration are also to be dealt with.

Thursday, Nov. 5th, the final day of the Fall Meeting, will offer two sessions by the Powder Metallurgy Committee, as well as the two nonferrous metallurgy meetings.

Southwest Conference to Probe Space Metals

Metals and Minerals for the Space Age is the theme of the Southwest Metals and Minerals Conference, to be held April 21-22, 1960, in the Ambassador Hotel, Los Angeles, Calif.

The Southern California, Reno, and San Francisco sections of AIME will co-sponsor the event, according to Henry T. Mudd, Chairman of the General Committee.

The program will consist of papers on the occurrence, properties, and processing of materials required for high speed flight. Materials such as boron beryllium, lithium, thorium, rare earths, and others will be discussed.

Plans Now Underway for 14th New England Regional Conference

Planning for the 14th New England Regional Conference slated for Boston in May 1960 has already begun.

The Conference Committee met at the Publick House in Sturbridge, Mass., June 30th, to decide on the general theme of next year's Conference, and to proceed accordingly.

New Developments in Metalworking is the title finally hit upon by the Committee. Topics to be covered include: high-speed forming techniques, special forming methods, and new developments in extrusion. The Committee has tentatively planned to have three technical sessions, plus a plant tour in the Boston area.

In view of the success of this year's 13th Regional Conference at Hartford in May, it was decided to organize the 1960 meeting along similar lines. Therefore, each technical session will start with a general review of the theory involved. That accomplished, the remainder of the time will be devoted to papers and panel discussions covering the practical aspects of the techniques under study.

Chairman of the 14th New England Conference Committee is J. P. Lynch, Jr., of The American Brass Co. Chairman of the Program Committee is W. D. Matthews, of the Gorham Manufacturing Co., while local arrangements are under the direction of C. M. Adams, Jr., of the Massachusetts Institute of Technology, who is also vice chairman of the Conference Committee.

As in the past, the 14th New England Regional Conference will be jointly sponsored by the Boston, Connecticut, and Hudson-Mohawk sections of the AIME.

J. H. HOLLOMON

Hollomon Elected Fellow of AAAS

John H. Hollomon, AIME director from the Institute of Metals Div., has been elected a Fellow of the American Academy of Arts and Sciences.

Dr. Holloman, thus, joins the select company of 1300 Americans "of genius and learning", plus 230 foreign and retired members who make up the Academy. He is currently manager of the Metallurgy and Ceramics Research dept. of the General Electric Research Laboratory, Schenectady, N. Y.

Dr. Holloman's other honors have included nomination as one of America's 10 outstanding young men of 1954 by the US National Junior Chamber of Commerce, and *Fortune Magazine's 1954* selection as one of the country's 10 leading young scientists in industry.

In 1946, Dr. Hollomon was awarded the AIME's *Rossiter W. Raymond Memorial Award* for the best paper published by a member under 33 years of age. He has more than 40 papers to his credit altogether, as well as a textbook on ferrous metallurgical design. More recently, Dr. Hollomon was granted the Rosenhain Medal for 1958 by the Institute of Metals, (England) for his outstanding contributions to metallurgy.

Stahl Translated

The Iron and Steel Institute (London) is now translating *Stal* (Steel), the Russian periodical of iron and steelmaking technology. The Institute has undertaken this complete English translation at the request of the UK's Department of Scientific and Industrial Research. The January issue of the translation is already out, and subsequent issues are being readied.

A year's subscription to *Stal* is £20.12, approximately $58. To order, write: *The Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London S.W. 1.*

Materials Research Committee Packed With AIME Members

A 14-man Committee on the Scope and Conduct of Materials Research, recently formed by the National Academy of Sciences' National Research Council contains no less than 10 AIME members! The group has been asked to determine how progress can be speeded in making better use of steel and its alloys, rare metals, ceramics, and other materials in the interest of national defense and industrial progress.

Dr. Clyde Williams, president of Clyde Williams & Co., Columbus, Ohio, has been named chairman of the committee. Formerly president and director of Battelle Memorial Institute, Dr. Williams served as chairman of the War Metallurgy Committee of the Academy-Research Council during World War II.

Members of the committee include A. J. Herzig, president of Climax Molybdenum Company of Michigan and chairman of the Materials Advisory Board; Dr. A. B. Kinzel, vice president in charge of research, Union Carbide Corp., and 1959 Past-President of the AIME; Thomas H. Miller, assistant director, US Bureau of Mines; Dr. John D. Morgan, Jr., consultant in Washington, D. C.; Dr. Thomas B. Nolan, director, US Geological Survey; Dr. Albert J. Phillips, vice president of the American Smelting & Refining Co.; Prof. Frederick Seitz, physics dept., University of Illinois, and chairman of the Committee on Perspective in Materials Research; Prof. Cyril S. Smith, of the Institute for the Study of Metals, University of Chicago; and David Swan, vice president in charge of research, the Linde Co., div. of Union Carbide Corp.

Semiconductors Conf. Begins Aug. 31

Aug. 31 -Sept. 2 are the dates for the conference on Properties of Elemental and Compound Semiconductors to be held at the Statler Hotel, Boston.

Sponsored by the IMD's Semiconductors Committee, the conference will include two days of technical sessions, plus a half-day tour of Lincoln Laboratory on the nearby campus of Massachusetts Institute of Technology. Work on radar, memory devices, transistorized digital computors, SAGE, and solid-state physics will be viewed there.

Registrants automatically will receive a copy of the conference's proceedings, including discussions. The fee is $10 to AIME members; and $15 for non-members. Information and forms may be obtained from *W. C. Hittinger, 555 Union Blvd., Allentown, Pa.* See the July issue of JOURNAL OF METALS, p. 475, for the technical program of the conference.

Plutonium Symposium Planned for France

An International Symposium on the Metallurgy of Plutonium will be sponsored by the Société Francaise de Métallurgie April 19-22, 1960, in Grenoble, France. Assisted in the program by the French Atomic Energy Commission, the French Society has scheduled a range of subjects, extending from the physics and metallurgy of plutonium to its technology and uses in nuclear combustion.

For information about registration or presentation of papers, contact: *Société Francaise de Métallurgie, 25 rue de Clichy, Paris; or E. Grison, Centre d'Etudes Nucleaires, Fontenay-aux-Roses (Seine).*

Mehl Receives Bendix Gold Medal at ASEE Meeting

R. F. MEHL

Robert F. Mehl received the Vincent Bendix Gold Medal from the American Society for Engineering Education in token of his contributions to research and teaching. Dr. Mehl, Dean of Graduate Studies at Carnegie Institute of Technology, accepted the award at the Society's annual meeting in Pittsburgh during June.

Earlier in June, Dr. Mehl, also head of the Metallurgical Engineering Dept. and Metals Research Laboratory at Carnegie Tech , was granted honorary degrees from both Case Institute of Technology and the University of Pennsylvania.

Among his other honors is included the AIME's *Douglas Gold Medal* "for distinguished achievement in nonferrous metallurgy" in 1945. He has also been the recipient of the Institute of Metals Division's *Mathewson Gold Medal* and award certificates in 1934, 1939, and 1944. He delivered the IMD's lecture at the 1936 Annual Meeting.

AIME Pacific Northwest Regional Conference

The 1959 Pacific Northwest Regional Conference held in Seattle, Wash., Apr. 16-18 brought a number of new and interesting metallurgical facts to light via technical sessions and papers.

The round-robin Conference, jointly sponsored by the Columbia, North Pacific, and Oregon sections of AIME, convened at the Olympic Hotel in Seattle. There, beginning on Friday morning, Apr. 17th, participants heard papers on extractive metallurgy and other subjects.

Douglas Baker, operating supt. of the Bunker Hill Metallurgical div., the Bunker Hill electrolytic zinc plant explained *Leaching Practice at The Bunker Hill Electrolytic Zinc Plant*. In other papers, H. Gordon Poole, the Colorado School of Mines, took part in an explanation of the *Interfacial Phenomena in the Solidification of Molybdenum*.

At Friday's luncheon AIME President Howard C. Pyle addressed the gathering. In the afternoon D. H. Polonis, of the School of Mineral Engineering, University of Washington, helped give a paper on the *Reaction Kinetics of Phase Transformations in Eutectoid Ti-Cu Alloys*.

Yale Award Given to Hibbard

Dr. Walter R. Hibbard, Jr., vice president of the AIME, has been given the 1959 Yale Engineering Association Award for the Advancement of Basic and Applied Science.

Dr. Hibbard, manager of the alloy studies section of the Metallurgy and Ceramics Research dept., General Electric Corp., received his doctorate in physical metallurgy from Yale in 1942. The award, presented at the Yale Club in New York City, cited Dr. Hibbard as a "scientist and engineer, metallurgist of international reputation . . . [who] has carried over into his industrial research affiliation a continuing interest in the teaching of our youth."

W. R. HIBBARD, JR.

Prof. Emeritus Mortimer F. Sayre (right) receives the AIME's Legion of Honor award from Robert E. Keith, Hudson-Mohawk section Chairman. Looking on is incoming chairman Prof. A. A. Burr, of Rensselaer Polytechnic Institute.

Prof. Sayre Awarded the AIME Legion of Honor

Mortimer F. Sayre was recently awarded the AIME's Legion of Honor in recognition of his 50 yrs continuous membership in AIME.

The insignia of the Legion of Honor are a gold pin and certificate. They were bestowed at the Hudson-Mohawk section meeting May 7th at Rensselaer Polytechnic Institute, Troy, N. Y. Mr. Sayre is professor emeritus of applied mechanics and former Chairman of the mechanical engineering dept. at Union College, Schenectady, N. Y. Prof. Sayre, the inventor of the Riehle-Sayre mirror extensometer, a device used in tensile testing, retired from his College post in 1955, after 41 years of service.

In addition to his teaching activities, Prof. Sayre also served as a consultant to the General Electric Co., Alco Products Co., and other organizations.

AIME Members High on List of AEC Contracts

The names of AIME members are liberally sprinkled throughout a recent listing of Atomic Energy Commission contracts let during April and May. The new, as well as renewed, contracts are for unclassified physical research at university and privately-owned laboratories.

In new contracts, Joseph Gurland, asst. prof. in the engineering div., Brown University, has been awarded $24,120 for Analysis of Structures of Two-Phase Alloys. A $31,900 contract was also given W. O. Philbrook, prof. of metallurgical engineering at Carnegie Institute of Technology, to study Thermal Conductivities of Inorganic Melts.

In contract renewals, E. R. Parker, prof. of metallurgy at the University of California, received $54,750 for research on the Creep of Alloys. Other renewals include: C. L. McCabe, Carnegie Institute of Technology, for Standard Free Energy of Formation of Certain Rare Earth Carbides; F. N. Rhines, Carnegie Institute, for Fundamental Study of the Early Stages of Sintering; R. Smoluchowski, Carnegie Institute, for Radiation Effects in Solids; Paul F. Kerr, Columbia University, for Alteration and Mineralization of Primary Uranium Deposits; Heinz Wilsdorf, Franklin Institute, for a Study of Radiation Effects in Solids by Electron Microscopy; Paul A. Beck, University of Illinois, for Annealing of Cold Worked Metals; J. T. Norton, Massachusetts Institute of Technology, for The Physical Metallurgy of Uncommon Metals; P. M. Hurley, MIT, for Investigations of Isotopic Abundances of Stontium, Calcium, and Argon in Certain Minerals; T. B. King, MIT, for Kinetics of Reactions Between Liquid Metals and Liquid Salts; Norman Brown, University of Pennsylvania, for The Effect of Stress on Recovery; N. A. Gokcen, University of Pennsylvania, for Vapor Pressures of Carbides; A. A. Burr, Rensselaer Polytechnic Institute, for Mechanism of the Effect of Rare Earth Solutes on the Allotropic Temperature of Zirconium; Sigmund Weissmann, Rutgers University, for Fundamental Study of Radiation Damage of Metals and Alloys by Means of Special X-ray Diffraction Methods; and R. B. Gordon, Yale University, for The Structure of Metallic Liquids.

AROUND THE SECTIONS

Lehigh Valley section held its annual dinner-dance at the Lebanon Country Club, Lebanon, Pa., May 22nd. Cocktails, a buffet dinner, and dancing made up the program for the evening. Nathan Brown, Section chairman, presided over the gathering, attended by 126 members, wives, and guests. Mrs. Brown headed the committee for program arrangements.

A field trip to the Friedensville mine of New Jersey Zinc Co. at Center Valley, Pa., is planned for the Section's next meeting at an unannounced date in September.

Washington D. C. section boarded a bus for a visit to the Chestnut Run Laboratories and Experimental Station of E. I. DuPont De Nemours & Co., Inc., in Wilmington, Del., on June 2nd.

After lunch, the group heard a talk on research conducted at the Station, looked in on the Lavoisier Library there, and visited the laboratory before departing for Washington.

Colorado Plateau section combined business with pleasure at its all-day meeting in the Beaumont Hotel, Ouray, Colo., June 20th.

A full schedule confronted the group, beginning with morning swimming and ending in midnight dancing. After picnic lunches, the men adjourned to a technical session while their wives and children went on sight-seeing tours. Following registration for the afternoon session, a short business meeting was held. Immediately thereafter, three papers were given.

With business out of the way, the meeting settled into socializing. A cocktail party, sponsored by Western Machinery Co., was served in the Beaumont Hotel ballroom from 6 pm to 7 pm. Dinner followed, and those who still had energy left after the long day danced from 9 o'clock 'til midnight.

Mark K. Shipman, second vice chairman of the Section, took care of program arrangements for the meeting.

Montana section joined with the Anderson-Carlisle Society on the Montana School of Mines' campus May 19th. Following the business meeting, members of the student Society presented papers.

Kenneth Fox spoke on the *Recognition of Igneous Rocks on Air Photos;* Aurelio Madrazo treated the subject, *Density Correlation of Hydrocarbon Systems;* Don Zipperian talked about *Flotation;* Carl A. Plate discussed *Identification of Non-Metallic Inclusions in Armco Ingot Iron Using Polarized Light;* and James D. Wallace revealed *Some Ideas on Improving Efficiency of Underground Rail Haulage.*

When the papers were finished, the students' wives served refreshments to the student-professional joint meeting.

Pittsburgh section's Mineral Industry Group heard J. L. Gillson, President-Elect of the AIME, at its dinner meeting Mar. 18th. Dr. Gillson, chief geologist for E. I. du Pont de Nemours and Co., talked about limestone, dolomite, bauxite, chromite, and manganese. Then, on May 6th, 100 members of the Group took an all-day field trip through the Aliquippa works of Jones & Laughlin Steel Corp. While there they saw the plant's LD furnace installation and its 44-in. hot strip mill that has programmed digital automatic control—the first automatic reversing roughing mill in the industry.

Minerals Beneficiation subsection of the Minnesota section heard a description of the Strategic-Udy process at its May 27th meeting. R. A. Blackburn, manager of the Strategic Materials section of Koppers Co., showed slides and gave cost figures for the Company's Niagara Falls pilot plant under the title *Strategic-Udy Direct Reduction Process.*

In other action, officers of the Subsection for the 1959-1960 season were elected. Fred H. Bunge is the new chairman, R. C. Ferguson, vice chairman; and R. A. Derby, secretary-treasurer.

Lima, Peru section celebrated its seventh anniversary with a cocktail-dinner-dance June 20th. Meanwhile, at the Section's regular monthly meeting May 25th the question of translating textbooks into Spanish was posed. An Education Committee has been appointed to look into the idea, and it is hoped that the Section will embark upon the project soon. Acting Secretary of the Section, Daniel Rodriguez, invites suggestions from any AIME member, particularly those in Latin America. Address your recommendations to Mr. Rodriguez at *Lord Nelson 171, Miraflores, Lima, Peru, South America.*

Niagara Frontier section installed its officers for 1959-1960 at its May 26th meeting in Buffalo. W. W. Stephens is the new chairman; C. H. Emery, vice chairman; J. D. Roach, secretary; and A. L. Cerda, treasurer. Named as the Section's Directors were D. G. Sturges, S. F. Urban, T. J. Voll, J. H. Brennan, B. E. Field, and M. C. Udy.

Adirondack section toured the Cabot Minerals plant in Willsboro, N. Y., June 27th. The combination plant and quarry visit was supplemented by a fireside symposium on maintenance at the Long Pond Restaurant and Bar. Cocktails and a charcoal broiled steak dinner rounded out the half-day meeting.

Management Conf. Meets Sept. 18-19 in Los Angeles

Listed below is the tentative program for the Seventh Engineering Management Conference, this year sponsored in part by The Metallurgical Society of AIME. The Statler Hilton Hotel in Los Angeles will be the scene of the Conference Sept. 18-19.

THURSDAY, SEPT. 17

Session I 9:30 a.m.

Development of Engineering Managers Chairman: Harry J. Kraig, asst. mgr., Ernst & Ernst, Inc.

Philosophy of Engineering Management, John L. Young, vice president, Engineering & Research, U. S. Steel Corp.

Developing Managerial Abilities, F. F. Bradshaw, president, Richardson, Henry & Bellows.

Session II 2:30 p.m.

Development of Engineering Managers Chairman: Bruce Old, Arthur Little, Inc.

Vice Chairman: Walter M. Pollit, Hughes Aircraft Co.

Management of Engineering and Scientific Programs, Louis Dunn, vice president and genl. mgr., Space Technology Laboratory, Inc. *Management of Engineering in an Industrial Organization,* J. Lee Atwood, president, North American Aviation, Inc.

Development of Engineering Managers in a Governmental Organization, Burton S. Grant, asst. genl. mgr. and chief engineer, Dept. of Water and Power, City of Los Angeles.

SOCIAL HOUR 6:00 p.m.

BANQUET 7:00 p.m.

Chairman: H. A. Bogle, Engr. Dept., E. I. du Pont de Nemours & Co., Inc.

Development of Engineering Statesmanship, the Honorable George D. Clyde, Governor, State of Utah.

FRIDAY, SEPT. 18

Session III 9:30 a.m.

New Concepts of Engineering Controls Chairman: Paul F. Lueth, supvr., Economics and Planning, Union Oil Center.

Vice Chairman: Robert A. Skinner, asst. chief engineer, Metropolitan Water Distr. of S. Calif., Los Angeles.

Control of the Engineering Function, Harry H. Goode, prof., University of Michigan; and tech. dir., Bendix Aviation Corp. *Development of Integrated Engineering Controls*—Case History, J. S. Sayer, technical coordinator, Engineering Dept., E. I. du Pont de Nemours & Co., Inc.

Development of Integrated Engineering Controls—Case History, Norman J. Ream, dir. of Systems Planning, Lockheed Aircraft Corp.

LUNCHEON 12:15 p.m.

Chairman: Henry O. Fuchs, Metal Improvement Co.

Why We Are Here, Glenn B. Warren, president, ASME; vice president and consultant, Turbine div., General Electric Co.

Session IV 2:30 p.m.

Engineering Planning

Chairman: C. Spence Purnell, distr. mgr., Westinghouse Electric Co. Vice Chairman: Karl E. Hegardt, Pacific Telephone & Telegraph Co.

Decision Making in Engineering, William L. Nichols, Arthur D. Little, Inc.

Engineering Programs for New Frontiers, George P. Sutton, chief scientist, Advanced Research Projects Agency, Dept. of Defense.

ASTM Proceedings for 1958 Is Out

The 1958 version of the American Society for Testing Materials' **Proceedings** is now available. Volume 58 of the ASTM Proceedings contains 1430 pages of technical papers, reports, discussion, and society activity.

Included are 51 technical papers, plus discussions, on a variety of research and testing materials. Seventy-four reports by technical committees also help make up the volume.

Cost of the Proceedings is $12 per copy; however, AIME members may obtain a discount by ordering through Irene K. Sharp, AIME Book Dept., 29 W. 39th St., New York 18, N. Y.

BOARD HONORS RETIRING INSTITUTE EMPLOYEES

Both well known to Institute members—Jim Ryan, above shown receiving a gold watch from AIME President Howard Pyle and Winifred Gifford, below, were honored on their retirement at the recent AIME Board of Directors meeting.

Below, Grace Pugsley Stickle, after 40 years of service in AIME Publications Department, was presented a silver vase by the AIME Board on the occasion of her retirement.

THE June 23rd meeting of the AIME Board of Directors marked the culmination of nearly 70 years of combined service to the Institute for three retiring members of the staff.

Mrs. Grace Pugsley Stickle, Mrs. Winifred Demarest Gifford, and Mr. James Ryan received the thanks and a "well done" from both the members of the Board and the staff at large.

The prize for longeveity goes to Mrs. Stickle, who served the AIME nearly 40 years—longer than any former staff member. From the day she first walked into the Institute in October 1919, she spent the entire time in the Publications dept. There she was responsible for many of the advertising functions—serving under no less than 12 advertising managers. "She has withstood the strain of changing immediate superiors and publications, both of which are somewhat inherent to the advertising department of a rapidly growing and diversified organization," read the Board of Directors citation.

Following a resolution of commendation, the Board presented Mrs. Stickle with a sterling silver vase, emblazoned with the AIME crest and words of appreciation.

Winifred D. Gifford, formerly secretary to AIME secretary, Ernest Kirkendall, put aside her pencil at this Board Meeting to accept the members token of gratitude. As it is written in the minutes: "RESOLVED, that the Board of Directors commends Winifred Demarest Gifford for her faithful service to the Institute from 1947 to 1959. The Board of Directors appreciates her unusual qualifications combining editorial proficiency with secretarial ability of high degree. The Board notes, further, her tremendous capacity for work, while practicing diplomacy and good judgment at all times."

With this, the Board presented her with a portable television set.

James Ryan—"Jim" to those acquainted with the face familiar to the AIME convention circuit—is the third member of the retiring triumvirate. Chief Shipping Clerk at the Institute since 1943, he is perhaps better known to members as Assistant Convention Manager. Noting his contributions to convention arrangements, the Board's resolution reads: "RESOLVED, that the Board of Directors commends James Ryan for his faithful service from 1943 to 1959. The Board of Directors appreciates particularly his performance at meetings, his ability to make friends for the Institute, as well as for himself, and his goodhearted willingness to help anyone with a problem."

With these words the Board presented him with a gold watch.

AIME to be Represented at ASTM San Francisco Meet

The AIME will be well represented at the American Society for Testing Materials' Third Pacific Area National Meeting and Apparatus Exhibit in San Francisco, Oct. 11-16.

Among the 53 technical sessions and 225 technical papers scheduled for the meeting will be found many member names. The Symposium on Newer Metals, slated for Thursday afternoon, Oct. 15th, and all day Friday, Oct. 16th, will be the biggest drawing card for metals men.

The Thursday afternoon session on Properties of Refractory Metals will feature L. L. France, research engineer at the Westinghouse Research Labs, Westinghouse Electric Corp., with a paper entitled *Universal High Temperature Testing Machine for Vacuum or Controlled Atmosphere.*

Marion Semchyshen, supervisor of metallurgy at the Climax Molybdenum Corp., will help give a paper on the *Mechanical Properties of Molybdenum and Molybdenum-Base Alloy Sheet.* F. C. Holden and R. I. Jaffee of the Battelle Memorial Institute will present a study of the *Tensile Properties of the Platinum-Group Metals.*

Friday's session on Nuclear and Light Metals, will see W. W. Beaver of the Brush Beryllium Co., Cleveland, co-authoring a paper on the *Effect of Purity and Manufacturing Variables on the Elevated Temperature Properties of Beryllium.* He will also discuss the *Creep Properties of Beryllium.* J. G. Goodwin of the Westinghouse Electric Corp., is taking part in an analysis of *The Effects of Heat Treatments on the Tensile and Corrosion Properties of Zircaloy-2.* O. N. Norman, associate professor of chemistry at Iowa State College will talk on the *Effect of Impurities and Alloying Addition on the Mechanical Properties of Yttrium.*

Part three of the Symposium will deal with the Processing of Newer Metals. W. T. Reynolds of Universal-Cyclops Steel Co. is co-author of a paper on the *Process Control of Molybdenum Melting and Fabrication.* Next scheduled is a paper entitled *Deoxidation and Denitrification Studies of Chromium and the Effect on Low Temperature Properties* by H. L. Levingston and N. J. Grant of Massachusetts Institute of Technology.

Processing and Properties of Tungsten will be the subject of a talk by C. H. Toensing, of the General Electric Co., Euclid, Okla.

The ASTM extends an invitation to all engineers to attend the Meeting. A $5 registration fee includes program and copies of papers. No charge is made to those wishing to attend only a session or two of the week-long Meeting.

Plan Symposium On Canadian Iron and Steel

A symposium on Iron and Steel in Western Canada will be held Sept. 8-9 in Edmonton, Alberta, Canada.

Theme of the Sept. 8th session is Resources and Markets for Steel in Western Canada. AIME members will include G. R. Heffernan, mgng. dir., Premier Steel Mills Ltd., with a paper on, *The Iron and Steel Industry in Western Canada;* and J. G. Parr, prof. of metallurgy, University of Alberta, whose presentation is, *Principles of Iron Reduction Processes.*

The Sept. 9th session will be devoted to the Technology of Iron and Steel Processes (with special reference to solid fuels). Speakers include W. M. Armstrong, prof. of metallurgy, University of British Columbia, *Electric Smelting Processes;* D. J. Hains, Hains Engineering Co., *Rotary Kiln Reduction Methods;* J. E. Rehder, Canada Iron Foundries Ltd., *Cupola Melting Process;* H. U. Ross, prof. of metallurgy, University of Toronto, *Sintering and Pelletizing;* and J. H. Walsh, Canadian Dept. of Mines and Tech-

Change of Address and Personals Form

To be sure that you receive your publications and correspondence promptly, please fill in the form below and send it to **The Metallurgical Society of AIME, 29 W. 39th St., New York 18, N.Y.:**

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Personals: Please list below your former company and title and your new title and company (or new work) for use in JOURNAL OF METALS. (Copy deadline for personals items is six weeks before date of issue.)

Former Company _____

Former Title _____ Length of Time There _____

New Company _____

New Company Address _____ Date of Change _____

New Title _____

Any recent activity that would be of interest to members:

_____

_____

_____

PROPOSAL FOR AIME MEMBERSHIP

I consider the following person to be qualified for membership and request that a membership kit be mailed to him:

Name of Prospective Member:

_____

Address

_____

_____

_____

Name of AIME Member:

_____

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_____

_____

JM

nical Surveys, *High Temperature Particle Reduction Processes.*

For more details, contact: W. A. Lang, Research Council of Alberta, Edmonton, Alberta, Canada.

Titanium Conference Planned at NYU

The welding, fabrication, heat treatment, and alloying of titanium will be the subject of the Fifth Annual Meeting on Titanium held by New York University's college of engineering, Sept. 14-15.

Engineers in research, industry, government are expected to attend the two-day meeting on the Bronx campus. Four of the 18 scheduled papers will be given over to the welding of titanium, while fabrication, heat treatment, and alloying will make up the remainder.

The conference is being presented by the metallurgical engineering dept. of NYU's college of engineering, and the University's office of Special Services to Business and Industry.

Registration fee is $15. Deadline for applications is Aug. 28th. Applications and further information may be obtained from *Dr. Harold Margolin, New York University, University Heights Center, New York 53, N. Y.*

Metallurgy Students in Exchange Program

Maurice Marcellin of Savoie, France, is the only metallurgy student among the 70 foreign visitors to the US for on-the-job training. The international student exchange is made possible by the International Association for the Exchange of Students for Technical Experience (IAESTE). The Engineers Joint Council has recently taken over the sponsorship of the Association.

Maurice is scheduled to begin work at J. E. Greiner Co. in Baltimore, Md., on Aug. 10th. This will be his American home until his October departure for France.

Two US metallurgy students, in turn, will be working in Europe this summer. Raymond Ekvall of the University of Pennsylvania will go to the Metallografiska Institutet in Stockholm, Sweden; while William Kern of New York University will journey to the Osterr. Alpine-Montangesellschaft in Vienna, Austria.

Altogether, nearly 100 American science and engineering students will be abroad this summer. However, this figure represents less than half of the more than 200 who applied for overseas placement. Since the program is based on reciprocity, the applications had to be denied because of the unwillingness of American industry to respond more fully. Even at that, foreign industries have allowed 30 more American students to enter their countries than the US has admitted.

For details on participating in the 1960 exchange, either as an industry sponsor or student traveler, contact: *Josef Wischeidt, Jr., Executive Secretary, US IAESTE Committee, c/o Engineers Joint Council, 29 W. 39th St., New York 18, N.Y.*

OBITUARIES

Harms, Viggo (member 1956) passed away on May 27, 1959. Mr. Harms was a process engineering specialist with Dorr-Oliver Inc. for over 33 years. A graduate of the Polytechnical College of Copenhagen, he joined the Dorr-Oliver subsidiary company in Germany in 1926. After serving there until 1932, he transferred to The Hague with the firm's staff. In 1941 Mr. Harms came to the United States and the parent company's Plant Engineering Division in Stanford, Conn.

NECROLOGY

Date Elected	Name	Date of Death
1944	Apell, Gideon A.	Apr. 27, 1959
1929	Bradley, Worthen	Unknown
1956	Harms, Viggo	May 27, 1959
1913	Hayes, Frank H.	Mar. 29, 1959
1930	Hoag, Clifford	Apr. 30, 1959
1912	Inouye, Tadashiro	Mar. 18, 1959
1953	Keay, William M.	Mar. 19, 1959
1940	Kildale, Malcolm B.	June 13, 1959
1917	Lindholm, Milton S.	June 12, 1959
1939	Marstrander, Henning	Mar. 31, 1959
1950	Mayer, Jon S.	May 30, 1959
1909	McAuliffe, Eugene Legion of Honor	June 2, 1959
1946	Parfet, Henry B.	May 29, 1959
1916	Steele, Chester H.	May 19, 1959
1920	Tolonen, Andrew W.	Apr. 11, 1959
1920	Wheelock, Charles W.	May 30, 1959

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on May 1, 1959 was 31,653; in addition 2,412 Student members were enrolled.

ADMISSIONS COMMITTEE

L. L. Seigle, Chairman; W. L. Brytczuk; F. B. Foley; T. D. Jones; Harold Margolin; Shadburn Marshall.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

Carlson, Carl W., Albany, Ore.
Carlson, John W., Pueblo, Colo.
Davies, Ted, Detroit, Mich.
DeSy, Albert L., Ghent, Belgium
Eaton, Paul B., W. Lafayette, Ind.
Fazzalari, Frank A., Yorktown Heights, N.Y.
Form, G. Willy, Cleveland, Ohio
Gatzek, Leo E., Los Angeles, Calif.
Gockstetter, George J., Chicago, Ill.
Harner, Harold R., Joplin, Mo.
Holub, Edward M., Newark, N.J.
Jarrett, Noel, New Kensington, Pa.
Kates, Leonard W., Bayside, N.Y.
Leanenworth, E. Kendrick, Coldwater, Mich.
Lichy, Edward J., Aliquippa, Pa.
Morgan, James E., Dearborn, Mich.
O'Donnell, John T., Anaconda, Mont.
Saxena, Mahesh N., Madison, Wisc.
Schees, Pierre E., Tilleur, Belgium
Sinason, H. Henry, Long Island, N.Y.
Sundberg, Carl W., Minneapolis, Minn.
Sweeney, Kenneth O., Anaconda, Mont.
Thompson, Thomas A., Weirton, W.Va.
Watson, George W., Weirton, W.Va.
Winter, Robert J., East Chicago, Ind.

Associate Members

Brandt, Lloyd J., Chicago, Ill.
Carpenter, Seth B., Marlboro, Mass.
Cline, Robert L., Grants, N. Mex.
Gifford, Melvin R., Anaconda, Mont.
Jacobson, Edwin C., Anaconda, Mont.
Lyon, Theodore R., Anaconda, Mont.
Main, William J., Skokie, Ill.
Terrien, Paul D., Pittsburgh, Pa.

Junior Members

Coulter, Thomas M., Emeryville, Calif.
Jensen, Elmer W., New York, N.Y.
Kelly, Walter H., Jr., Anaconda, Mont.
Silverman, Ronald, New York, N.Y.
Starner, Bernard M., New Kensington, Pa.
Wells, James E., Ann Arbor, Mich.
Wirtz, Theodore R., Kansas City, Mo.

CHANGE OF STATUS
Associate to Member

Corey, Clark L., Belleville, Mich.
Ridgeway, Robert H., Jr., Joliet, Ill.

REINSTATEMENT—CHANGE OF STATUS
Junior to Member

Barnett, William J., Cincinnati, Ohio

RE-ELECTION

Hornbogen, Erhard, Monroeville, Pa.

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Coming Events

Aug. 23-25, Conference on the Fracture of Engineering Materials (ASM), Rensselaer Polytechnic Institute, Troy, N.Y.

Aug. 31-Sept. 2, AIME Semiconductors Conference, Statler Hotel, Boston, Mass.

Sept. 8-9, Symposium on Iron and Steel in Western Canada, The Metallurgy and Coal Divisions, Canadian Institute of Mining and Metallurgy and the Research Council of Alberta, Edmonton, Alberta, Canada.

Sept. 10, AIME, NOHC Chicago Section, Golf Party and Dinner, Midlothian Country Club, Chicago.

Sept. 16-17, Annual Meeting of the American Die Casting Institute and Die Casting Research Foundation, Edgewater Beach Hotel, Chicago.

Sept. 18-19, Seventh Engineering Management Conference co-sponsored by The Metallugical Society of AIME, ASME, AIEE, and others. Hotel Statler, Los Angeles.

Sept. 21-22, 57th Fall meeting of the Steel Founders' Society of America, at the Homestead, Hot Springs, Va.

Sept. 28-Oct. 1, Fall Meeting of American Welding Society, Sheraton-Cadillac Hotel, Detroit.

Oct. 5, AIME, NOHC Chicago Section Fall Dinner Meeting, Phil Smidt's Restaurant, Hammond, Ind.

Oct. 7-9, Sixth National Symposium on Vacuum Technology of the American Vacuum Society, Sheraton Hotel, Philadelphia.

Oct. 8-9, AIME, NOHC Southwestern Section, Fall Meeting, Pere Marquette Hotel, Peoria, Ill.

Oct. 9, AIME, NOHC Eastern Section, 13th Annual Conference, Warwick Hotel, Philadelphia.

Oct. 11-16, Third Pacific Area National Meeting of the American Society for Testing Materials, Forum on Reactor Materials, Sheraton-Palace Hotel, San Francisco.

Oct. 16-17, AIME, NOHC Southern Ohio Section, Fall Meeting, Deshler-Hilton Hotel, Columbus, Ohio.

Nov. 2-5, Fall Meeting of The Metallurgical Society of AIME, Morrison Hotel, Chicago.

Nov. 6, AIME, NOHC Pittsburgh Section, Off-the-Record Meeting, Penn-Sheraton Hotel, Pittsburgh.

Nov. 10, AIME, NOHC Buffalo Section, 10th Annual Meeting, Royal Connaught Hotel, Hamilton, Ontario, Canada.

Nov. 16-20, Conference on Magnetism and Magnetic Materials, Sheraton Hotel, Philadelphia.

Dec. 1-5, Symposium on Structural Changes in Metals and Alloys, co-sponsored by the Indian Institute of Metals and Dept. of Metallurgy, Indian Institute of Science, Bangalore, India.

Dec. 2-4, AIME 17th Electric Furnace Steel Conference, Hotel Cleveland, Cleveland, Ohio.

Feb. 14-18, 1960, AIME Annual Meeting, Hotel McAlpin and Hotel Statler, New York.

Feb. 16-19, 1960, Symposium on Hydrometallurgy, *Wet Processing of Minerals and Industrial Products,* The Australasian Institute of Mining & Metallurgy, Adelaide, Australia.

Mar. 15-21, 1960, Third International Conference on Nondestructive Testing, Tokyo, Mar. 15-18; Osaka, Mar. 21.

Apr. 4-6, 1960, AIME 43rd National Open Hearth Steel Conference and Blast Furnace, Coke Oven, and Raw Materials Conference, Palmer House, Chicago.

Apr. 21-22, 1960, AIME Southwest Metals and Minerals Conference, Ambassador Hotel, Los Angeles, Calif.

June 13-15, 1960, First International Powder Metallurgy Conference, Hotel Biltmore, New York, under joint auspices of AIME and MPIA.

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"THE NATIVE HOLLANDER WEARS WOODEN SHOES."

A Bell Telephone Laboratories experiment in noise appraisal

"The native Hollander wears wooden shoes."

"Nebraska has no seacoast."

"The daisy is a common wildflower."

As these syllables, words and sentences come in over the telephones, stand-ins for millions of Bell System subscribers rate them for clarity of reception.

From these tests, Bell Telephone Laboratories engineers determine what is objectionable noise, and work to minimize it in telephone circuits. They begin by tape recording background noise associated with working telephone circuits. Test statements of appropriate length and content (such as those above) are read onto a second tape, and both are fed onto the test circuit under carefully controlled conditions. A third tape, of normal room noise, is played through a loudspeaker in the test lab.

Several hundred listeners, meeting in small groups several times a day for weeks at a time, are then asked to rate the effect of noise on transmission of the various simulated telephone calls.

For the Bell System, the results of the study will become part of the over-all transmission objectives. At Bell Laboratories, they will influence apparatus and systems development work.

Noise is a major distraction of modern day living. It is also an enemy of the Bell System. In a telephone receiver during a call, it might be power line hum, switching or thermal noise, or perhaps atmospheric static. Bell Laboratories spends a great deal of time, effort and money to keep this extraneous noise from becoming annoying and to assure you of a trouble-free connection.

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